Guidebook—Excursions C-1 and C-2

COLORADO PLATEAU REGION

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COLORADO PLATEAU REGION

BY

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COLORADO PLATEAU REGION

By Herbert E. Gregory

ABSTRACT

As illustrated by areas in southern Utah and northern Arizona on both sides of the Grand Canyon, the Colorado Plateau region is characterized by sharply defined plateaus, mesas, buttes, and deep, narrow canyons, most of them developed in sedimentary strata that lie nearly flat. Within the Grand Canyon some 6,000 feet (1,830 meters) of Archean, Algonkian, Cambrian, Devonian, and Carboniferous rocks are exposed. Bordering the canyon on the north more than 8,000 feet (2,440 meters) of Triassic, Jurassic, Cretaceous, and Tertiary beds (including lavas) are displayed in the High Plateaus. The dominant structural features are three northward-trending faults, which outline the Markagunt and Paunsaugunt Plateaus, and a flat-topped upwarp, the Kaibab Plateau. The topographic features have developed during at least two cycles of erosion, each initiated by regional uplift. In altitude the region lies between 2,000 and 10,000 feet (610 and 3,050 meters); consequently the climate ranges from semitropical to temperate and the plant zones from subtropical to subalpine. The region, once the home of Puebloans ("Cliff Dwellers") and of Indians (Piutes), was explored by Spaniards and American fur traders and was colonized by adherents of the Mormon Church. The chief industry is stock raising.

EXPLANATORY NOTE

Existing knowledge of the geologic features of southwestern Utah and northwestern Arizona is based on reconnaissance topographic and geologic surveys (chiefly of the period 1870–1885) supplemented by detailed surveys of areas in the Virgin and Colorado Valleys. Therefore many of the descriptions here given are subject to revision, and the interpretations are tentative, only the Grand Canyon being adequately known. Geologic features of special interest along the route chosen for the excursion are listed in the itinerary. Descriptions of Zion Canyon, Bryce Canyon, and Grand Canyon are presented merely in outline. For these the geology is satisfactorily treated in readily accessible pamphlets issued by the National Park Service and other agencies.

GEOGRAPHY

TOPOGRAPHY

Southern Utah and northern Arizona constitute a region of plateaus outlined by fault scarps trending north and south, by erosion escarpments trending east and west, and by canyons which, except for the Colorado, trend generally north and south. Other than the volcanic masses of Mount Trumbull, the San

Francisco Mountains, and scattered low cones, there are no "mountains" as this term is generally applied. The highlands are plateaus, tables, benches, or steps rather than mountains, hills, or domes, and the streamways are canyons—narrow or wide, deep or shallow—rather than river flats, bottoms, swales, or meadow lands. The canyons and plateaus alike are developed on a stupendous scale, and for the region as a whole "the canyon lands" and "the plateau country" are equally appropriate terms. The plateaus are arranged in two series extending eastward from the Great Basin country of Nevada. The higher series—the High Plateaus—embraces the Markagunt (mar-kah′gunt) (including the Colob Terrace) and Paunsaugunt (paun-saw′gunt) Plateaus, with their subdivisions, and the Kaiparowits (ky-pair′o-wits) Plateaus east of the Paria (pah-re′a) River. The lower series, which borders the Colorado River and extends northward to the stepped cliff face of the High Plateaus, includes the Shivwits (sheev′wits), Uinkaret (you-in-kah′ret) Kanab (kay-nab′) Kaibab (ky′bab), and Paria Plateaus. South of the Colorado the extensions of the Uinkaret, Kanab, and Kaibab Plateaus are combined in the Coconino (co-co-ne′no) Plateau. The Markagunt, Paunsaugunt, and Kaibab Plateaus reach altitudes exceeding 9,000 feet (2,745 meters); the Shivwits, Uinkaret, Kanab, and Paria Plateaus stand at about 6,000 feet (1,830 meters), and the Coconino at 7,000 feet (2,135 meters). Except for short streams in the vicinity of Cedar City that flow westward and dwindle to extinction in the Escalante Desert, the drainage of the lower plateaus and the rim of the High Plateaus is tributary to the Colorado River. The drainage of the broad, flat tops of the Markagunt and Paunsaugunt Plateaus is carried northward by the far-reaching Sevier River in its roundabout course to Sevier Lake. At the edge of desert lowlands streams issuing from gorges in the plateaus form oases—the habitable lands of southern Utah. (See pl. 1.)

CLIMATE

The climate of the plateau country ranges according to the altitude from semitropical to temperate. At St. George (altitude 2,800 feet, or 853 meters) the mean annual temperature is 58.9° F., the mean maximum, 77.0°; and temperatures of 98° to 116° are recorded between April and September. Here figs, pomegranates, and almonds grow well. At Springdale (3,900 feet, or 1,189 meters), near Zion National Park, the climate is similar. At Cedar City, Kanab, and generally below the rim of the High Plateaus, at altitudes of about 5,000 feet (1,525 meters), the summers are hot, but the winters are con-

siderably colder. The rim and the top of the High Plateaus have long, cold winters, but the summer temperature may exceed 90°. At Alton (7,000 feet, or 2,135 meters), near the head of the Kanab Valley, the mean annual temperature is 43.2° F.; the highest 94°, and the lowest −20°. Temperatures below 0° F. have been recorded from November to April, and killing frosts during every month of the year. The climate of the Kaibab anp Coconino Plateaus as represented by measurements at Grand Canyon station (6,866 feet, or 2,090 meters) is characterized by a mean annual temperature of 47.3° F., a mean maximum of 61°, a mean minimum of 47.3°, extremes of 98° (July) and −22° (January), and killing frosts in all months except July and August. Within the Grand Canyon below about 4,000 feet (1,220 meters) the winters are mild, but on cloudless days from April to October the solar heat is concentrated, and its radiation from bare rocks is very uncomfortable, even after sunset.

The annual precipitation within canyons and on lands at altitudes below 6,000 feet (1,830 meters) and on the High Plateaus ranges from 9 to 14 inches (0.23 to 0.36 meter). Only at Alton has an annual rainfall greater than 20 inches (0.51 meter) been measured. At Bryce Canyon (altitude 8,000 feet, or 2,440 meters) the estimated annual precipitation is 12 inches (0.30 meter); at Grand Canyon, about 17 inches (0.42 meter); on the Kaibab Plateau, probably more. In the Grand Canyon much of the rainfall evaporates before it reaches the bottom of the canyon. Snow falls everywhere in southern Utah and northern Arizona in amounts ranging from a trace in the bottom of the Grand Canyon to 7 inches (0.18 meter) in Virgin Valley, 22 inches (0.55 meter) at Kanab, and more than 70 inches (1.78 meters) on the Paunsaugunt, Kaibab, and Coconino Plateaus. On the lower lands it disappears soon after falling, but in forests and other protected places, at altitudes above 7,000 feet (2,135 meters), it may last through the spring and block roads as late as June. Showers, both rain and snow, are rare, brief, and widely spaced. Southern Utah is an arid region in which dry air and clear skies predominate. The average number of days each year on which as much as 0.01 inch falls is only 42 at Zion Canyon, 48 at Kanab, 58 at Cedar City and Grand Canyon, and 60 to 70 on the High Plateaus. There is no persistent seasonal distribution of precipitation. May and June are the driest months but in some places not much drier than August and September. July is one of the wettest months. The distribution of rainfall and its scantiness are factors unfavorable to agriculture except by irrigation. The whole Colorado Plateau country finds most use as a cattle and sheep range.

Showers and the melting of snow quickly fill drainage channels, but they are quickly emptied. Within a few days or even a few hours the streams may change from torrents to rills or entirely disappear. The widely branched Virgin River, the only northern tributary of the Colorado that is perennial throughout its course, fluctuates in run-off between 25 and 15,000 cubic feet (0.7 and 420 cubic meters) a second. The Sevier (se-veer′) River, on the High Plateaus, is perennial and fluctuates less widely.

VEGETATION

The plateau country presents a large variety of floral regions and plant associations because of its great range in temperature (above 100° F. to below zero), in precipitation (about 8 to 23 inches, or 0.20 to 0.57 meter), in soil (alkaline to meadow loam), in altitude (3,000 to 10,000 feet, or 915 to 3,050 meters), in topographic features (low level flats, narrow canyons, broad plateaus), and in kinds of rock exposed (basalt, sandstone, shale, limestone, gypsum, gravel, and silt). The flora ranges from subtropical (Lower Sonoran), characterized by the creosote bush (*Covillea tridentata*) and the Joshua tree (*Clistoyucca brevifolia*) to subalpine (Hudsonian), in which aspens, firs, and spruce are dominant. The general north-south trend of lofty plateaus and deep-cut canyons favors the intermingling of floras typical of the western United States with those typical of northern Mexico. In the deepest canyons desert plants grow in the bottoms and pines and firs on the rims. Of about 4,000 species and varieties of vascular plants, some are restricted to small areas, but many others, such as oaks, piñons, and species of *Artemisia*, have a wide vertical and horizontal range. With reference to their suitability for grazing—the primary use of plants in the plateau country—the conservation branch of the United States Geological Survey has recognized seven types of vegetation corresponding roughly with altitude. The most desirable type ("subalpine") furnishes adequate forage for 37 animal units (each unit equals 1 head of cattle or 8 head of sheep) to the square mile (14 units to the square kilometer) during the grazing season. The least desirable type provides for 2 animal units to the square mile (0.8 unit to the square kilometer).

About the rim of the High Plateaus, on the lower plateaus, and in many canyons the most conspicuous and most widespread plants are sagebrush (*Artemisia*), juniper (*Juniperus utahensis*), piñon (*Pinus edulis*), and yellow pine (*Pinus ponderosa*). Associated with the yellow pines are such shrubs as oak brush (*Quercus gambelii*), service berry (*Amelanchier alnifolia*), chokecherry, gooseberry, currant, manzanita (*Arctostaphylos pungens*), and

Oregon grape (*Odostemon repens*); also some 20 species of grasses and many flowering annuals, including asters, columbines, gentians, flax, goldenrods, phlox, blue bells, and the characteristic Indian paint brush (*Castilleja*) and Sego lily (*Calochortus nuttallii*). At the highest altitudes, particularly on the Kaibab Plateau, the conspicuous forest trees are aspen (*Populus tremuloides*), spruce (*Picea engelmanni*), and fir (*Pseudotsuga taxifolia*). At lower altitudes, associated with thin stands of piñon, juniper, and sage, the most conspicuous shrubs are rabbit brush (*Chrysothamnus*), bitter brush (*Cowania neomexicana*), Brigham tea (*Ephedra antisyphilitica*), yucca, and such attractive flowering annuals as bee weed (*Cleome lutea* and *Cleome serrulata*) and evening primrose. On the most arid bench lands shadscale (*Atriplex canescens*), matchweed, black brush (*Coleogyne ramosissima*), and hardy grasses predominate. Cottonwoods and willows grow along washes, and ferns are common around springs and water seeps in the canyon walls. Most of the tops of the Markagunt, Paunsaugunt, Kaibab, and Coconino Plateaus have been set aside as national forests—reservations designed to conserve timber, protect watersheds, and prevent overgrazing of pasturage.

Descriptions of the vegetation of the plateau country are included in reports by Tidestrom (29),[1] the United States Forest Service (30), and the National Park Service (31).

FAUNA

The wild animals most commonly seen in the Colorado Plateau country are squirrels, chipmunks, gophers (including the interesting "prairie dogs"), lizards, rabbits, hawks, and many delightful song birds. There are several kinds of rats and mice. In the forested areas porcupines, woodchucks, and skunks are not uncommon, and a few beavers remain in protected meadow lands. The predatory animals—mountain lions, wolves, and wild cats in the timbered regions and coyotes in more open spaces—that once made stock raising a hazardous occupation have been largely exterminated by Government trappers. Of the large game animals that made southern Utah a favorite hunting ground for the Indians, the antelope, the elk, and most of the mountain sheep have been exterminated, but the deer still live on the High Plateaus. On the Kaibab Plateau, where they are protected by law, the herds number about 30,000 deer. The plateau country is the home of some unique species of squirrels, land snails, and insects. An interesting result of recent

[1] The numbers in parentheses refer to the bibliography on pp. 36–38.

studies is the discovery that the Grand Canyon is a faunal boundary of importance.

Treatises on the animal life of southern Utah and northern Arizona have been written by Barnes (1), Woodbury (34), and Merriam (20).

SETTLEMENTS

The earliest known man in the southwestern United States is represented by artifacts in association with the bones of an extinct species of bison at Folsom, New Mexico, and with the remains of an ancient ground sloth at Lovelock, Nevada. The earliest known archeological remains sufficient to identify a culture are those of the Basket Makers—a long-headed, semihunting, semiagricultural people who occupied areas scattered from southern Utah to Mexico and attained their highest culture in the San Juan Valley. They lived in caves and perishable dwellings and subsisted on wild animals hunted with traps, javelins, and spears, supplemented at first by corn and later by squash and beans. They made no true pottery but were skilled craftsmen in the making of baskets and weaving of textiles in fiber, fur, and feathers. The Basket Makers were followed by the Puebloans (Cliff Dwellers)—a round-headed stock who founded settlements in the Colorado River drainage basin, some of which exist to-day. The Puebloans were a sedentary people, skilled in the conservation of water and in the cultivation of corn, beans, and squashes. They reached their cultural peak about 1100 A. D. and left a record of excellence in architecture, in village organization, and in the making of pottery. Their large cliff houses and their skillfully made, artistically decorated bowls have attracted wide attention. All the living Puebloans and most of the ruined settlements of Basket Makers and Cliff Dwellers are south and east of the Colorado River. They are described in publications of the Bureau of American Ethnology.

Hunting bands of Indians (Navajos?) were found on the Coconino Plateau by the Spanish explorer Cárdenas, the discoverer of the Grand Canyon (1540). The Domínguez-Escalante expedition (the first white men in Utah, 1776) encountered Indians in the Coal, Virgin, Kanab, and Paria Valleys. Jedediah Smith, fur trader, established business relations with Indians along the Virgin River in 1826. The southern Utah pioneers of 1850–1860 found permanent or temporary Indian settlements at nearly all places where food was readily attainable by hunting, by gathering of seeds and roots, and by cultivation of small patches of corn, beans, and squashes. The Indians then living on and south of the High Plateaus, numbering perhaps 2,000, were members of the great Utah (Uta, Ute) tribe, who, with their

linguistic relatives, the Piutes (pie-utes′), occupied Colorado, Utah, and Nevada. The Piutes of southern Utah were peaceable clans who built no permanent houses but maintained communities at sites favorable for agriculture and winter quarters. They subsisted chiefly on game—deer, rabbits, lizards, and grasshoppers—grass seed, piñon nuts, and the tuberous "yamp" (*Carum gairdneri*), supplemented by corn raised on semi-irrigated patches of land. With the disappearance of deer and the destruction of edible seed and root plants by the introduction of cattle and sheep, their customary food was no longer obtainable, and satisfactory adjustment to a new mode of living proved impossible. The once strong tribe is now represented by a few families supported by the Government on the Shebit Reservation in Santa Clara Valley and the Kaibab Reservation near Kanab.

Permanent white settlement in southern Utah resulted from plans made by the Mormon Church for the expansion of its economic, cultural, and ecclesiastical interests. Soon after the establishment of "Zion" (Salt Lake City) in 1847, scouts were sent southward across the High Plateaus and along the base of the "southern" mountains to select sites where water and arable land favored colonization. During the decade 1850–1860 small communities were established at Cedar City (1851), New Harmony (1852), Virgin City (1858), and Toquerville (1858). Systematic colonization began in 1861, when "several hundred families" moved from northern Utah counties to lands along the Virgin River, where the climate, soil, and water supply seemed suitable for the growth of much needed cotton. St. George (1862) was the center for this new "Dixie land" and the site for the church temple. With the coming of additional families, settlements were developed along the Virgin River at Washington, Toquerville, Grafton, Rockville, and Springdale. Farther east and on oases at the base of the High Plateaus small groups of families established themselves at Short Creek, Pipe Springs (1863), Kanab (1864), Mount Carmel (1864), Glendale (1864), and Alton (1865). Many of these weak pioneer settlements were abandoned during 1866 and 1867, in consequence of raids by the Navajo (nah′va-ho) Indians, but during the decade 1870–1880 there was substantial growth, and several new settlements—Johnson (1871), Orderville (1875), Lees Ferry, and Tuba (1878)—were established. Hurricane and La Verkin are relatively new communities organized as the result of the development of an irrigation project.

The population of southwestern Utah in 1930 was, in Iron County, 7,227 (2.2 per square mile, or 0.8 per square kilometer); Washington County, 7,420 (3 per square mile, or 1.2 per square

kilometer); Garfield County, 4,642 (0.9 per square mile, or 0.3 per square kilometer); Kane County, 2,235 (0.5 per square mile, or 0.19 per square kilometer). It is almost exclusively Nordic. The chief industry is stock raising.

GEOLOGY

SEDIMENTARY ROCKS

[Pl. 1]

Except for the Archean and Algonkian formations at the bottom of the Grand Canyon the Colorado Plateau province is essentially a region of sedimentary rocks—a pile of Paleozoic, Mesozoic, and Tertiary strata, chiefly sandstone, more than 10,000 feet (3,050 meters) thick and exposed over an area exceeding 150,000 square miles (388,500 square kilometers). The sedimentary beds of the region are representatives of broadly defined stratigraphic groups that extend northward in Utah to the Uinta (You-in'tah) Mountains, eastward into Colorado and New Mexico, southward to central Arizona, and westward beyond the Utah-Nevada boundary line. Like the Permian (Kaibab) limestone that now constitutes the surface rock on both sides of the Grand Canyon, beds of Triassic, Jurassic, and Tertiary age, similar to those exposed in the cliffs of the High Plateaus and in buttes and mesas in northern Arizona, are believed to have been once continuous across the Colorado, providing a cover twice as thick as the present canyon is deep. The stratigraphic section exposed reveals evidence of extended intervals of earth movements and erosion. In the walls of the Grand Canyon the Algonkian beds rest on the eroded surface of a mountain range and are unconformably overlain by the Cambrian; the Ordovician and Silurian are lacking, the Devonian is present in patches only, and ancient surfaces of erosion are represented by unconformities at the base of the Redwall (Mississippian) and the base and top of the Supai (Permian). In the rocks that form the plateaus north and south of the Colorado there are unconformities of regional significance between the Kaibab (Permian) and the Moenkopi (mo-en-ko'pi) (Triassic), between the Moenkopi and the Shinarump (shin-air'ump) (Triassic), and between the Cretaceous and the Tertiary, besides breaks that indicate shorter lapses between other formations.

Most of the Paleozoic rocks and all of the Algonkian and the Archean appear only in the Grand Canyon and the mouths of its tributary canyons, whereas Mesozoic and Cenozoic beds are well displayed in the plateau country as a whole. It has there-

fore been found convenient to treat the canyon beds and the plateau beds as separate groups, using the Kaibab limestone, the uppermost Permian, as the division plane. At no viewpoint is it possible to see the entire series—Archean to Tertiary.

Generalized regional reports on the sedimentary rocks of the plateau country have been made by Powell (24), Dutton (9), Gilbert (10), Darton (4), and others, and more detailed reports by Gregory (14), Gregory and Moore (12), Gilluly and Reeside (11), and Longwell and others (17). Special studies of the Kaibab have been made by Noble (22), of the Kaibab and Moenkopi by Reeside and Bassler (25), of the Shinarump by Gregory (13), and of the Cretaceous by Richardson (26) and Spieker and Reeside (28). Reconnaissance studies of the Grand Canyon by earlier geologists have been supplemented by Noble (21) and White (33).

Rocks of the Grand Canyon

[Pl. 2; figs. 1, 2]

ARCHEAN

Vishnu schist and granitic intrusions.—The Vishnu schist, which forms the walls of the Granite Gorge of the Colorado River, consists of quartz schist, mica schist, and hornblende schist intruded by quartz diorite and granitic pegmatite. A detailed study of these rocks has been made by Noble and Hunter (23).

ALGONKIAN

Grand Canyon series.—The formations of Algonkian age, separated from the Vishnu schist by a great unconformity, include limestones, shales, and quartzites classed as divisions of the Unkar and Chuar groups of the Grand Canyon series. They constitute the remnant, preserved by faulting that brought it below the surface of erosion, of 12,000 feet (3,660 meters) of once widespread sediments of pre-Cambrian time. In ascending order the formations of the Unkar group are the Hotauta (hoe-tau′ta) conglomerate, Bass limestone, Hakatai (hack′a-tie) shale, Shinumo (shin′u-mo) quartzite, and Dox sandstone. The overlying Chuar group has not yet been separated into named units.

As the Algonkian is widely scattered along some 50 miles (80 kilometers) of canyon and most exposures show only incomplete sections that are inconspicuous from the canyon rim, its constituent formations are not differentiated on Figure 1. Along the Kaibab trail (Bright Angel Point to Yaki Point) the

Bass limestone, Hakatai shale, and Shinumo quartzite are exposed (fig. 2). The largest areal exposure of Chuar and Unkar rocks is visible from Cape Royal. The Hotauta conglomerate (6 feet (1.83 meters) or less thick) and the Dox sandstone (more

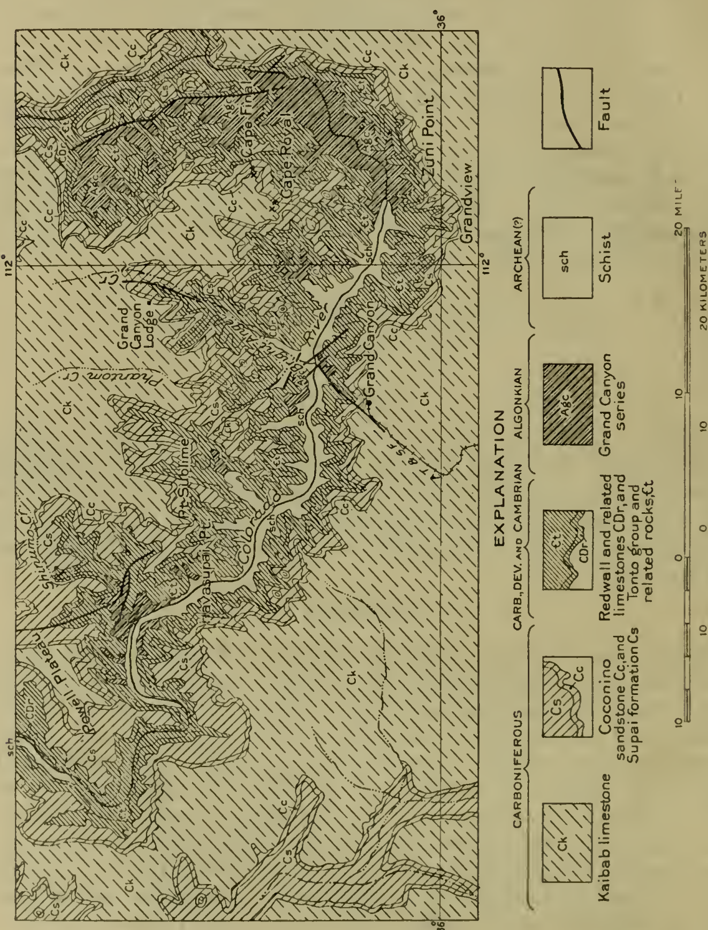


FIGURE 1.—Geologic map of the Kaibab section of the Grand Canyon

than 2,000 feet (610 meters) thick) are typically exposed near Shinumo Creek, some 20 miles (32 kilometers) below the mouth of Bright Angel Creek. The composition, structure, and stratigraphy of the Algonkian formations are described in publications by Walcott (32), Noble (21), and White (33).

CAMBRIAN

Tapeats sandstone.—The Tapeats (tah-peets′) sandstone is a resistant formation, 225 feet (68 meters) thick, that forms a cliff in the canyon wall on which has been developed the Tonto Platform. It is the lowest horizontal bed in the canyon and rests unconformably on a surface produced by erosion of the Unkar group and the Vishnu schist. It is a pebbly, slabby quartzitic grit.

Bright Angel shale.—Conformably above the cliff made by the Tapeats sandstone is a slope developed on the Bright Angel shale, a greenish-gray sandy shale from which fossils of Upper Cambrian age have been collected.

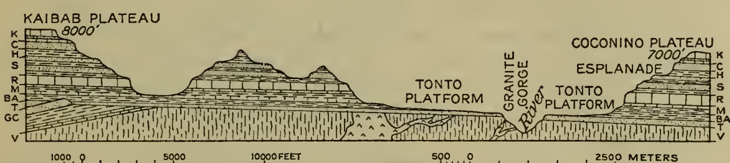


FIGURE 2.—Generalized section across the Grand Canyon between the Kaibab and Coconino Plateaus. K, Kaibab limestone; C, Coconino formation; H, Hermit shale; S, Supai formation; R, Redwall limestone; M, Temple Butte and Muav limestones; BA, Bright Angel shale; T, Tapeats sandstone; GC, Grand Canyon series; V, Vishnu schist. (After L. F. Noble, U. S. Geol. Survey Bull. 549.)

Muav limestone.—The Muav (mwav′) limestone consists characteristically of a thin-bedded bluish-gray, mottled fossiliferous limestone with which are interbedded lenses of buff and green shale. Its thickness averages about 100 feet (30 meters).

DEVONIAN

Strata of Ordovician and Silurian age do not occur in the Grand Canyon. The Devonian is represented only by patches of pale-purple sandy limestone less than 100 feet (30 meters) thick known as the Temple Butte limestone. Where this formation is lacking, horizontal Carboniferous beds (Redwall limestone) rest on horizontal Cambrian (Muav) limestone, separated only by an erosional unconformity.

CARBONIFEROUS

Redwall limestone (*Mississippian*).—The Redwall limestone, 550 feet (158 meters) thick, consists essentially of dense blue-gray crystalline pure limestone with obscure planes of bedding. It forms a single cliff, the highest in the lower part of the canyon,

the face of which is stained red by products of weathering derived from the overlying red shales.

Supai formation (*Permian*).—The Supai (soo′pie) formation is a series of massive cross-bedded fine-grained red-stained sandstones, interbedded with sandy red shale and including a few beds of calcareous sand, limestone conglomerate, and cherty limestone. The total thickness exceeds 800 feet (244 meters). The alternating sandstones and shales give a steplike form to the outcrop. The Supai formation is separated from the Redwall limestone below and the Hermit shale above by planes of unconformity. Its deposits are those of river flood plains within which impressions of fernlike plants (*Walchia*) and tracks of land animals have been preserved.

Hermit shale (*Permian*).—The Hermit shale is a succession of thin layers of red sandy friable shale remarkably alike in color, composition, and bedding. The thickness averages about 300 feet (91 meters). From the Hermit shale have been collected impressions of ferns, cone-bearing plants, insect wings, and tracks of salamanders (?).

Coconino sandstone (*Permian*).—The Coconino sandstone ("Aubrey sandstone" of the older literature) forms a buff vertical wall, 300 to 350 feet (91 to 107 meters) high, just below the rim of the canyon. It is characterized by uniform fineness and purity of grain, by persistent cross-bedding on a huge scale, and by general massiveness. Most of its beds have the form of interlocking wedges, 10 to 75 feet (3 to 23 meters) thick; a few horizontal beds appear at the base. As at present interpreted, the Coconino is largely an eolian deposit. The cross-bedding laminae preserve the tracks of ancestral amphibia.

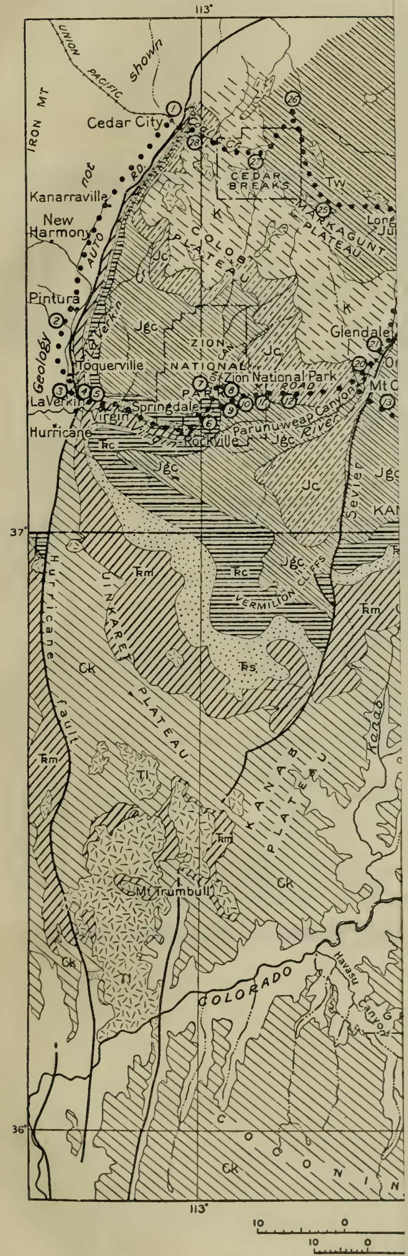
Kaibab limestone (*Permian*).—The Kaibab limestone is the highest stratum in the walls of the Grand Canyon. It is also the basal formation of the plateaus north and south of the Colorado River. (See pl. 1.)

Rocks of the Plateaus

[Pl. 1; fig. 3]

PERMIAN

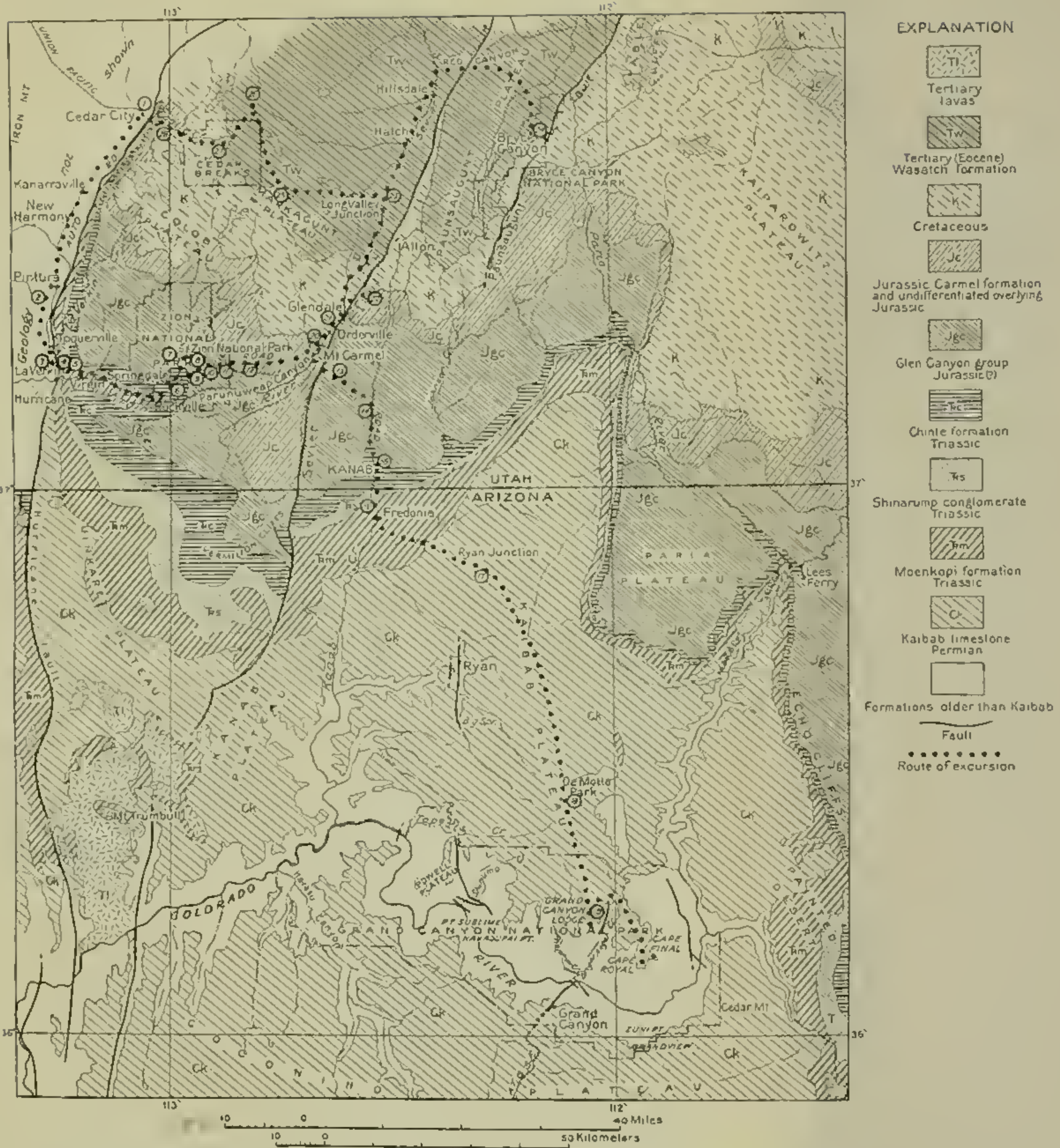
Kaibab limestone.—The Kaibab limestone ("Aubrey" limestone; "Upper Aubrey" of the older literature) is exceptionally widespread. With few interruptions it forms the surface rock of the Shivwits, Uinkaret, Kanab, and Kaibab Plateaus, north of the Colorado, and the Coconino Plateau, south of the river. From the Echo Cliffs to the Grand Wash Cliffs, a distance of about 130 miles (208 kilometers), it constitutes the rim rock



SKETCH GEOLOGIC MAP OF P.

Based on reconnaissance surveys by Dut

Gran



SKETCH GEOLOGIC MAP OF PART OF THE COLORADO PLATEAU REGION

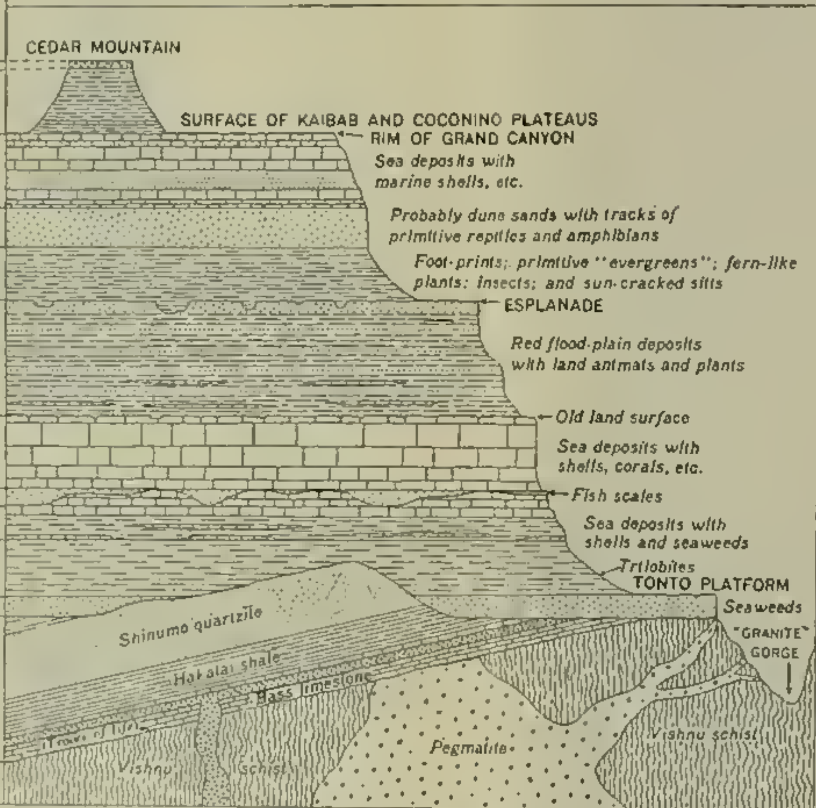
Based on reconnaissance surveys by Dutton, Gilbert, Darton, and Gregory. For formations within Grand Canyon see Figure 1.

COLORADO PLATEAU REGION

Era	Period and Epoch	Group and Formation	Kind of Rock	Prevailing Color	Thickness in Feet
MESOZOIC	TRIASSIC	Shinarump congl.	Conglomerate	Brown	25
		Moenkopi fm	Shale and sandstone	Red	480
		UNCONFORMITY			
PALEOZOIC	CARBONIFEROUS — PERMIAN	Kaibab limestone	Limestone and sandstone	Gray, buff, and red	525
		Coconino sandstone	Sandstone	Light buff	350
		Hermit shale	Sandy shale	Red	225
		Supai formation	Sandstone and shale with some limestone	Red and gray	825
		UNCONFORMITY			
	CARBONIFEROUS — MISS.	Redwall limestone	Limestone	Gray stained red	450 to 500
	DEVONIAN	Temple Butte ls.	Limestone and sandstone	Pale purplish	0-36
		GREAT UNCONFORMITY			
	CAMBRIAN	Tonto group: Muav limestone	Sandy shale and limestone	Gray	100
		Tonto group: Bright Angel shale	Sandy shale	Greenish gray	450 to 650
		Tonto group: Tapeats sandstone	Sandstone	Brown	225
		GREAT UNCONFORMITY			
PROTEROZOIC	ALGONKIAN	Unkar and Chuar groups of Grand Canyon series	Sandstone and shale with some limestone; contains sheets and dikes of lava	Mostly red	0 to 12000
		GREAT UNCONFORMITY			
	ARCHEAN	Vishnu schist	Schist, granite, and gneiss	Dark gray	Not known

GENERALIZED COLUMNAR SECTION C

Era	Period and epoch	Group and formation	Kind of rock	Prevailing color	Thickness in feet
Mesozoic	Triassic	Shinarump congl.	Conglomerate	Brown	25
Mesozoic	Triassic	Moenkopi fm	Shale and sandstone	Red	480
		UNCONFORMITY			
Paleozoic	Carboniferous, Permian	Kaibab limestone	Limestone and sandstone	Gray, buff and red	525
Paleozoic	Carboniferous, Permian	Coconino sandstone	Sandstone	Light buff	350
Paleozoic	Carboniferous, Permian	Hermit shale	Sandy shale	Red	225
Paleozoic	Carboniferous, Permian	Supai formation	Sandstone and shale with some limestone	Red and gray	825
		UNCONFORMITY			
Paleozoic	Carboniferous, Miss	Redwall limestone	Limestone	Gray stained red	450 to 600
Paleozoic	Devonian	Temple Butte ls.	Limestone and sandstone	Pale purplish	0-35
		GREAT UNCONFORMITY			
Paleozoic	Cambrian (Tonto group)	Muav limestone	Sandy shale and limestone	Gray	100
Paleozoic	Cambrian (Tonto group)	Bright Angel shale	Sandy shale	Greenish gray	450 to 650
Paleozoic	Cambrian (Tonto group)	Tapeats sandstone	Sandstone	Brown	225
		GREAT UNCONFORMITY			
Proterozoic	Algonkian	Unkar and Chuar groups of Grand Canyon series	Sandstone and shale with some limestone; contains sheets and dikes of lava	Mostly red	0 to 12000
		GREAT UNCONFORMITY			
Proterozoic	Archean	Vishnu schist	Schist, granite, and gneiss	Dark gray	Not known



GENERALIZED COLUMNAR SECTION OF ROCKS FORMING THE WALLS OF THE GRAND CANYON

After L. F. Noble.

of the Grand Canyon. It is predominantly a gray or buff cherty fossiliferous arenaceous limestone with some interbedded sandstone and locally gypsum at the base (Harrisburg gypsiferous

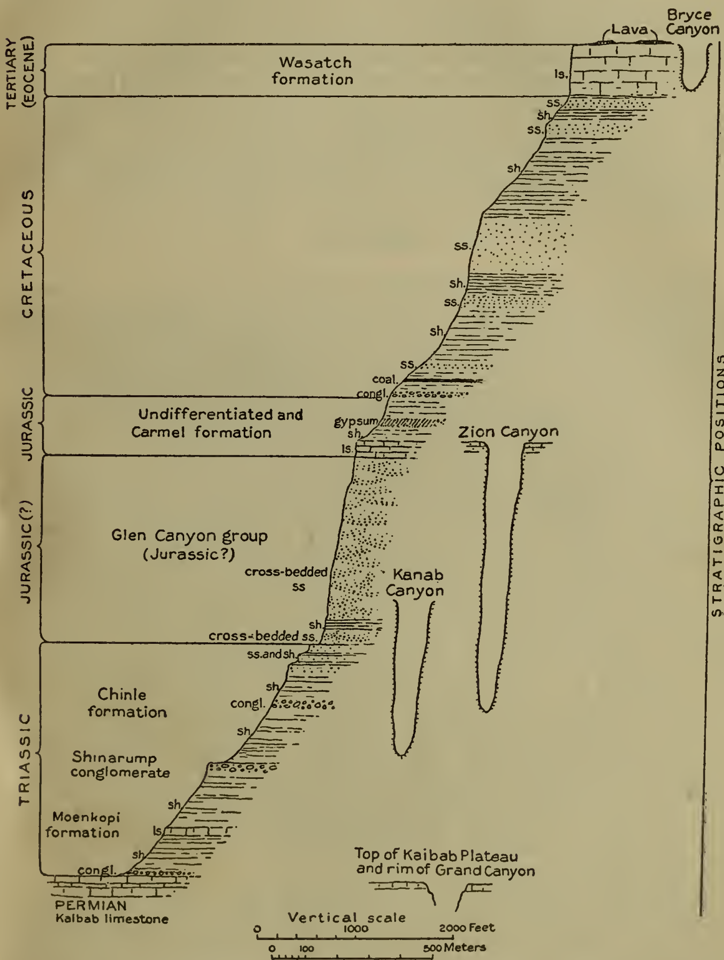


FIGURE 3.—Generalized section of sediments along the rim of the High Plateaus

member, "*Bellerophon* limestone"). In outcrops the Kaibab limestone forms ragged, nearly vertical cliffs with recessed grooves along the edges of the less resistant beds. The Per-

mian age of the formation is attested by a marine fauna comprising some 80 species, among them *Productus ivesi*, *Productus occidentalis*, *Pustula subhorrida*, and *Meekella pyramidalis*, considered representative of the "normal Kaibab fauna." The limestone is 800 to 1,000 feet (244 to 305 meters) thick in the Virgin River Valley, 500 to 600 feet (152 to 183 meters) along the rim of the Grand Canyon, 600 to 700 feet (183 to 213 meters) in the northern part of the Kaibab Plateau, and 200 to 300 feet (61 to 91 meters) about Flagstaff, on the Coconino Plateau. The Kaibab is conformable with the underlying Coconino (Permian) and unconformable with the overlying Moenkopi (Lower Triassic).

TRIASSIC

Moenkopi formation.—The Moenkopi formation is a series of red-brown, brick-red, gray, white, and yellow gypsiferous sandy shales with interbedded layers of earthy yellow limestone in the lower part and a conglomerate of variable composition at the base. It lies unconformably above the Kaibab limestone (Permian) and like the Kaibab is present over large areas north and south of the Colorado River. As displayed along the route of the excursion (outlined in the itinerary, pp. 29–34), the Moenkopi forms regularly banded cliffs along the Virgin River and at Fredonia. In the series of bands that are predominantly shades of red and brown, two are particularly conspicuous—a band of yellow fossiliferous limestone about 500 feet (152 meters) from the base, resistant enough to form a cliff, and a band of white gypsiferous sandy shale 500 to 600 feet (152 to 183 meters) higher. The measured thickness of the formation is 1,775 feet (540 meters) at Virgin City, 400 feet (122 meters) in the Little Colorado Valley, and 480 feet (146 meters) at Cedar Mountain, on the south rim of the Grand Canyon. The thickening westward is accompanied by an increase in amount of limestone and a change in part from arid-climate terrestrial deposits to marine deposits, with which are associated such fossil forms as *Meekoceras* aff. *M. mushbachanum*, *Bakewellia* sp., *Myalina* n. sp., and *Pseudomonotis* n. sp.

Shinarump conglomerate.—The Shinarump conglomerate is a stratum of conglomerate and coarse sandstone, containing fragments of fossil wood, that unconformably overlies the Moenkopi. Its position as a resistant bed between the soft shale of the Moenkopi and Chinle formations gives it particular prominence, though in few places is it more than 100 feet (30 meters) thick. Throughout the plateau province it is a cliff maker.

Chinle formation.—Conformably overlying the Shinarump conglomerate is a series of variegated shales, arkosic sandstones,

and thin cherty limestone conglomerates defined as the Chinle (chin-lee′) formation. The shales include much volcanic ash (bentonite). Near the entrance of the Zion National Park and at Kanab they constitute brilliantly colored banded slopes of shale broken by cliffs developed on the sandstone members. Within the plateau province the Chinle ranges in total thickness from 400 feet (122 meters) to about 1,000 feet (305 meters). A distinctive feature of the Chinle is the presence of fossil wood, which near Rockville, east of Kanab, and at many places in northern Arizona occurs in sufficient abundance to constitute "petrified forests." Besides the petrified wood (chiefly *Araucarioxylon arizonica* and *Woodworthia arizonica*), fossils from the Chinle include fish and reptilian teeth and species of *Unio*.

JURASSIC

Glen Canyon group (*Jurassic?*).—The Glen Canyon group consists essentially of huge piles of sandstone characterized by cross-bedding on an exceptional scale. As expressed in the topography the group is the outstanding maker of cliffs and canyon walls. It forms the walls of Zion Canyon, of lower Parunuweap (pah-roon′u-weep) Canyon, and in part of Kanab Canyon, and the lofty "White Cliffs" that rim the Markagunt and Paunsaugunt Plateaus. In most places, as, for example, in Kanab Canyon, the Glen Canyon group is divisible into three formations—at the bottom the Wingate sandstone, lying perhaps unconformably on the Chinle; an intermediate formation, the Kayenta (kay-en′ta), consisting of calcareous shale and limestone; and at the top the Navajo sandstone. In the High Plateaus the total thickness of the group exceeds 2,000 feet (610 meters).

Carmel formation.—The Carmel formation, the basal formation of the San Rafael group, is a series of hard gray limestones and calcareous shales 100 to 250 feet (30 to 76 meters) thick. It conformably overlies the Navajo sandstone of the Glen Canyon group. Along the route of the C–1 excursion it is well displayed on the Zion-Mount Carmel highway, in Meadow Brook Canyon, and particularly at Mount Carmel Junction. Fossils from the limestone beds include *Pentacrinus* stems, *Trigonia* sp. like *T. americana*, *Camptonectes bellistriatus*, and small *Ostrea*.

Undifferentiated Jurassic (?).—Above the Carmel formation is a series of beds with a total thickness of about 250 feet (76 meters) that consists of poorly consolidated pinkish gypsiferous sands overlain in turn by massive gypsum, thin fossiliferous limestones, and sandy shales. The position of these beds in the time scale and their relation to the overlying Cretaceous have

not been satisfactorily established. Probably they represent the rest of the San Rafael group and the overlying Morrison formation. Along the route of excursion C–1 these beds are well displayed in Parunuweap Valley south of the village of Mount Carmel.

CRETACEOUS

In the plateau province beds of Cretaceous age attain thicknesses of more than 3,000 feet (915 meters). They constitute long shale slopes, high sandstone cliffs, and vertical canyon walls in the zone between the friable topmost Jurassic strata and the resistant Tertiary limestones that rim the High Plateaus. The beds contain fossils of early Colorado, middle Colorado, late Colorado, and Montana age. The Cretaceous of the Markagunt Plateau, exposed along the route of excursion C–1 at Meadow Brook, in Parunuweap Canyon, and along Coal Creek, has not been subdivided but probably includes the formations recognized by Gregory and Moore (12) on the east edge of the Paunsaugunt Plateau—the Dakota (?) sandstone, Tropic shale, Straight Cliffs sandstone, Wahweap sandstone, and Kaiparowits formation. In the position of the Dakota (?) is an inconspicuous gravel bed.

As described by Richardson (26) the Cretaceous beds of Colob Plateau comprise 300 to 400 feet (91 to 122 meters) of sandstone, shale, and coal resting on basal conglomerate, 1,000 feet (305 meters) of drab shale, 1,000 feet (305 meters) of buff sandstone and drab shale—all three of Colorado age—and buff sandstone and shale of Montana age resting unconformably on the lower beds.

TERTIARY

Wasatch formation.—The Tertiary sediments of the plateau district are included within the Wasatch formation, of Eocene age. They consist of highly colored beds of limestone, shale, and sandstone, resting on a basal conglomerate that is unconformable with underlying Cretaceous strata. In most places the thickness of the series as exposed is 400 to 500 feet (122 to 152 meters), but the maximum thickness probably exceeds 1,500 feet (457 meters). On the Markagunt and Paunsaugunt Plateaus the most conspicuous part of the formation is the pink limestone that forms the "Pink Cliffs" and gives scenic interest to such places as Red Canyon, Bryce Canyon, and Cedar Breaks.

IGNEOUS ROCKS

In the plateau province intrusive igneous rocks are represented by widely separated laccoliths and volcanic necks and by some granitic and basic dikes. Along the itinerary selected for the

excursion from Salt Lake andesite is exposed at the base of the Pine Valley Mountains, and granite is associated with schists and gneisses at the bottom of the Grand Canyon. Extrusives associated with extinct volcanoes are represented by lava cones, cinder cones, flows, and breccias on the Markagunt, Table Cliffs, Shivwits, Uinkaret, Kanab, and Coconino Plateaus and in Ash, La Verkin, Virgin, Kanab, and Johnson Valleys. The distribution of the igneous masses seems to be independent of the faults.

The two major volcanic fields include Mount Trumbull and the San Francisco Mountains. In the Trumbull district basalt was erupted at two periods. The remnant lavas of the first period now cap mesas of Lower Triassic rocks; those of the second period, the product of more than 170 vents, rest on Kaibab limestone that forms the surface of the plateau. Associated with them are some 150 low cones that are only slightly affected by erosion. In the San Francisco volcanic field evidence of three general periods of eruption has been recognized—basalt flows, eruptions of andesites and rhyolites that built the lofty peaks, and basaltic lavas and ash. Here, as at Mount Trumbull, lavas of the first period (basalt) overlie Triassic beds, and those of the latest period rest on the rock that forms the present surface of the Coconino Plateau. Likewise, the San Francisco field includes many cinder cones so fresh in appearance as to suggest activity within historic time. The basalt flows to be seen on both the routes of the excursions from Salt Lake City and Flagstaff are all remarkably fresh and youthful. A flow near Toquerville rests on river gravel; one that filled the canyon of the Parunuweap above Glendale is being eroded; at Navajo Lake lava still obstructs the drainage; and generally on the Markagunt Plateau the lavas are merely piles of fresh rock spread here and there on the surface

General descriptions of igneous rocks of the plateau country are given by Dutton (8) and Gilbert (10); a detailed study of the San Francisco field has been made by Robinson (27) and of the Granite Gorge by Noble and Hunter (23).

STRUCTURE

The structure of the Colorado Plateaus in the Grand Canyon region is relatively simple. In an east-west cross section the outstanding features are the Hurricane fault, the Sevier fault, and the Paunsaugunt fault—three master displacements that cut the plateaus into blocks trending north and south—and the broad, lofty Kaibab upwarp. (See pl. 1 and fig. 4.) A north-south cross section (fig. 5) reveals the dependence of topo-

graphic features on the regional sedimentary beds. Faults with vertical throw exceeding 1,000 feet (300 meters) interrupt the beds in Coal Canyon without much modifying the topography, and faults involving stratigraphic breaks of 50 to 200 feet (15 to 60 meters) are associated with the larger faults and appear

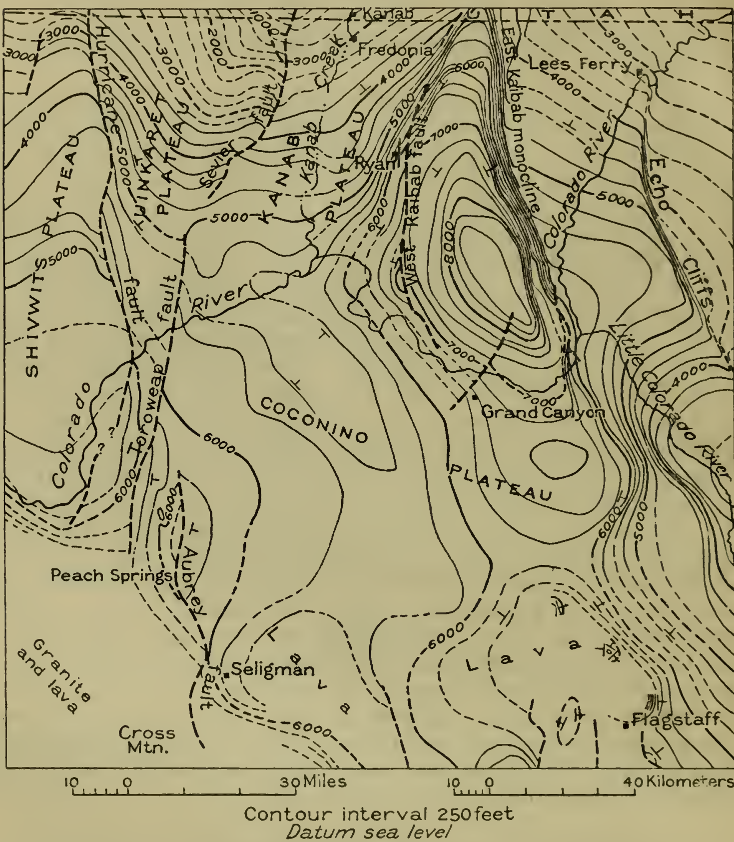


FIGURE 4.—Map showing deformation of strata in the Grand Canyon region by contour lines at the base of the Kaibab limestone. (After N. H. Darton.)

also at the west base of the Kaibab Plateau, on the rim of the Grand Canyon, at Mount Carmel, in the Kanab Canyon, in the lower Virgin Valley, and at a few other places. The strata are upwarped in the chain of low domes that cross the Virgin River south of Toquerville and are sharply downwarped on the east flank of the Kaibab uplift. Folds also are associated with

the major faults. To a remarkable extent the strata between the great faults and immediately adjoining folds are undisturbed. Dips of less than 2° are characteristic. Regional uplift and differential erosion rather than faults are the primary causes of the huge plateau blocks, the towering cliffs, and the profound canyons.

HURRICANE FAULT

As shown by dislocation of strata, the Hurricane fault extends from a point near Beaver, 45 miles (72 kilometers) north of Cedar City, southward across the Colorado River. Throughout its length of about 200 miles (322 kilometers) it is marked by escarpments at the base of the Markagunt Plateau and the Colob Terrace, continued southward as the Hurricane Cliffs. For long distances it appears as a clean continuous fracture or fault zone less than 100 feet (30 meters) wide, but at Toquerville a branch extends into the upthrown block, and in places on the Shivwits Plateau the downthrown block is shattered for about a mile from the fault line. The faults in Coal Creek and Kanarra (kan-ar′ra) Canyons may be genetically related to the major faulting. At the Colorado River the estimated vertical displacement is 1,500 feet (457 meters); at Hurricane, where the Carmel formation (Upper Jurassic) abuts against the base of the Kaibab (Permian), the downthrow exceeds 6,000 feet (1,830 meters); between Pintura and Kanarraville, where the Cretaceous and possibly the Tertiary are sunk to the level of the Kaibab, it may be even more. (See fig. 6.) The rock at the summit of the walls in Zion Canyon is the

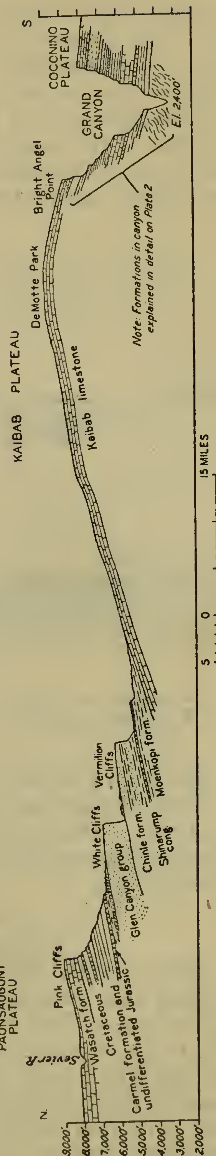


FIGURE 5.—Generalized cross section from Red Canyon (Paunsaugunt Plateau) across the rim of the High Plateaus and Kaibab Plateau to the Grand Canyon.

stratigraphic equivalent of that in the lowlands west of La Verkin. The lateral displacement revealed by erosion is about 10 miles (16 kilometers). Movement on the Hurricane fault occurred at two periods separated by an interval long enough for the development of mature topography and, in places, the obliteration of the earlier fault scarps. Lava flows that crossed the fault line in the interfault cycle have been broken and their western parts downthrown about 300 feet (91 meters) at the

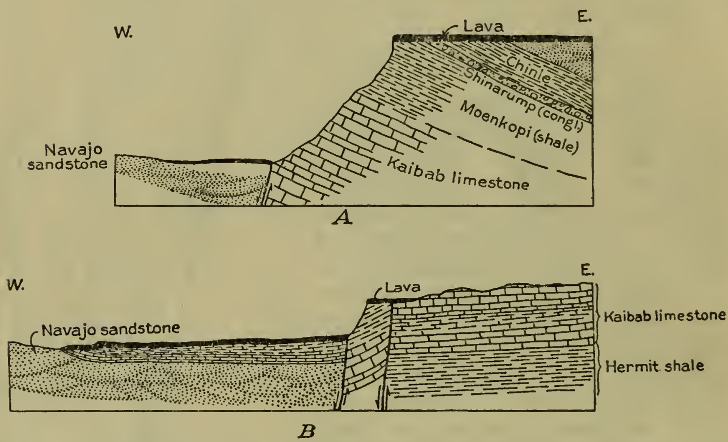
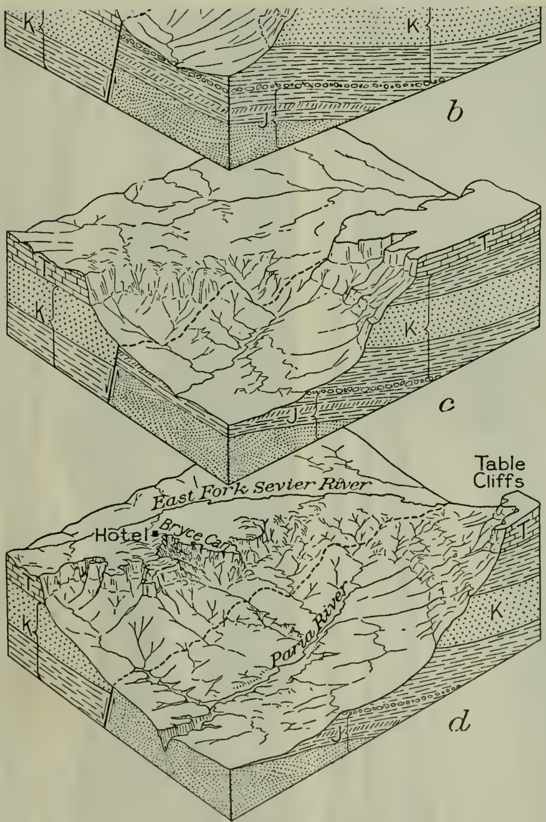


FIGURE 6.—Generalized cross sections of Hurricane fault. *A*, Near Pintura; *B*, at the Virgin River. (After Huntington and Goldthwait)

Virgin River and perhaps 1,000 feet (305 meters) at Kanarraville. Both the earlier and the later faulting occurred in post-Eocene time. The topographic effects of the Hurricane fault have been discussed by Dutton (8, 9) and by Huntington and Goldthwait (15).

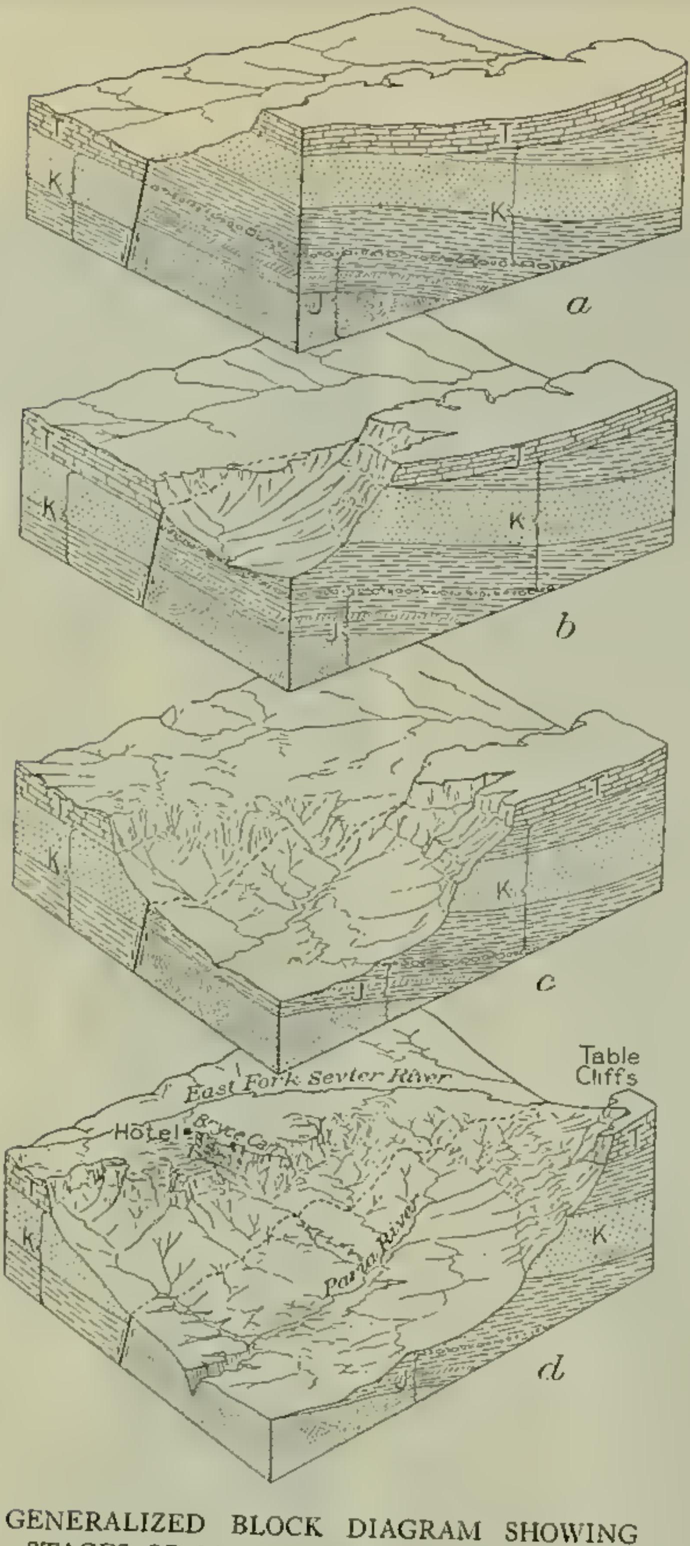
SEVIER FAULT

The Sevier fault, the structural boundary line between the Markagunt and Paunsaugunt Plateaus, has been traced for a distance of about 220 miles (354 kilometers) from the central High Plateaus southwestward to its point of disappearance near Mount Trumbull and probably continues as the Toroweap (tor′o-weep) fault, which crosses the Grand Canyon at Vulcan's Throne. The fault is predominantly a single shear in a nearly vertical plane, but at Alton branch faults in the downthrown



GENERALIZED BLOCK DIAGRAM SHOWING STAGES OF EROSION AT BRYCE CANYON

T, Tertiary; K, Cretaceous; J, Jurassic. *a*, Tertiary and underlying beds are displaced along Paunsaugunt fault; drainage is northward on the downthrown block. *b*, Tertiary cliffs on upthrown block are worn back by headwaters of the Paria River, which flows with steep gradient to the Colorado; weak Cretaceous beds are eroded. *c*, Beds both in the upthrown and the downthrown blocks are eroded. *d*, Present topography; the surface of beds along the Paria River that originally were part of the upthrown block now stands about 2,000 feet below the original surface of the downthrown block. (After Gregory and Moore.)



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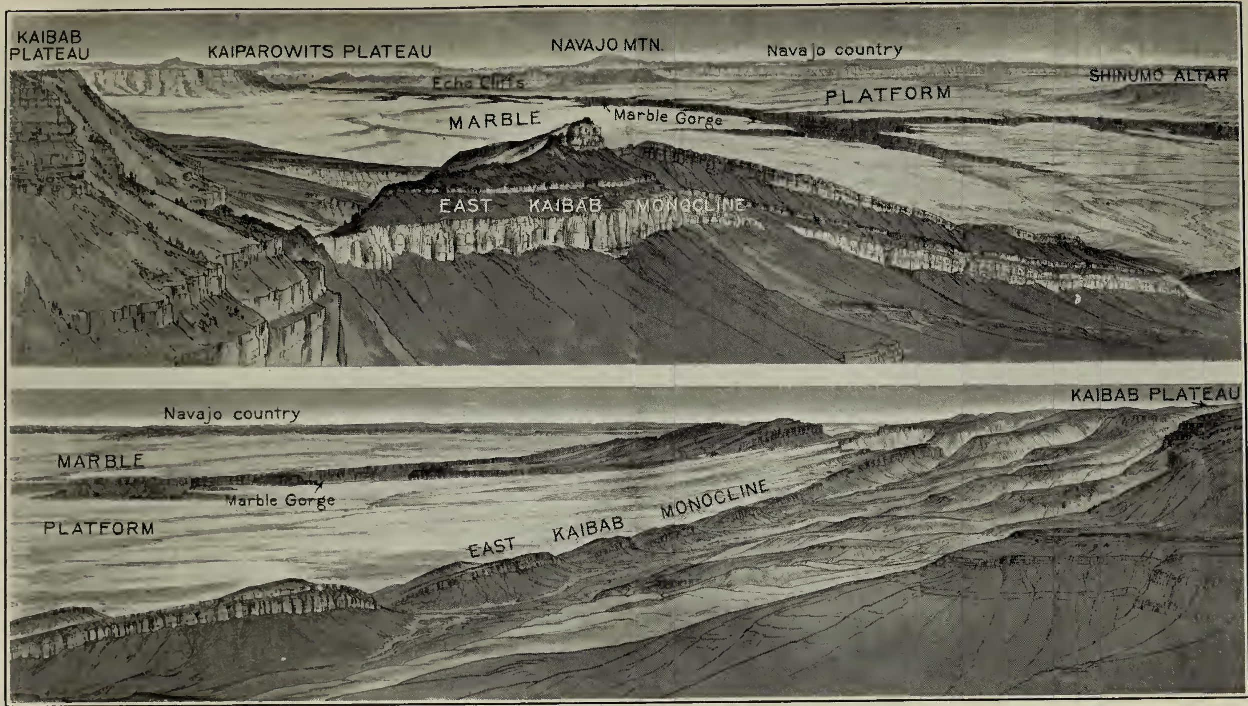
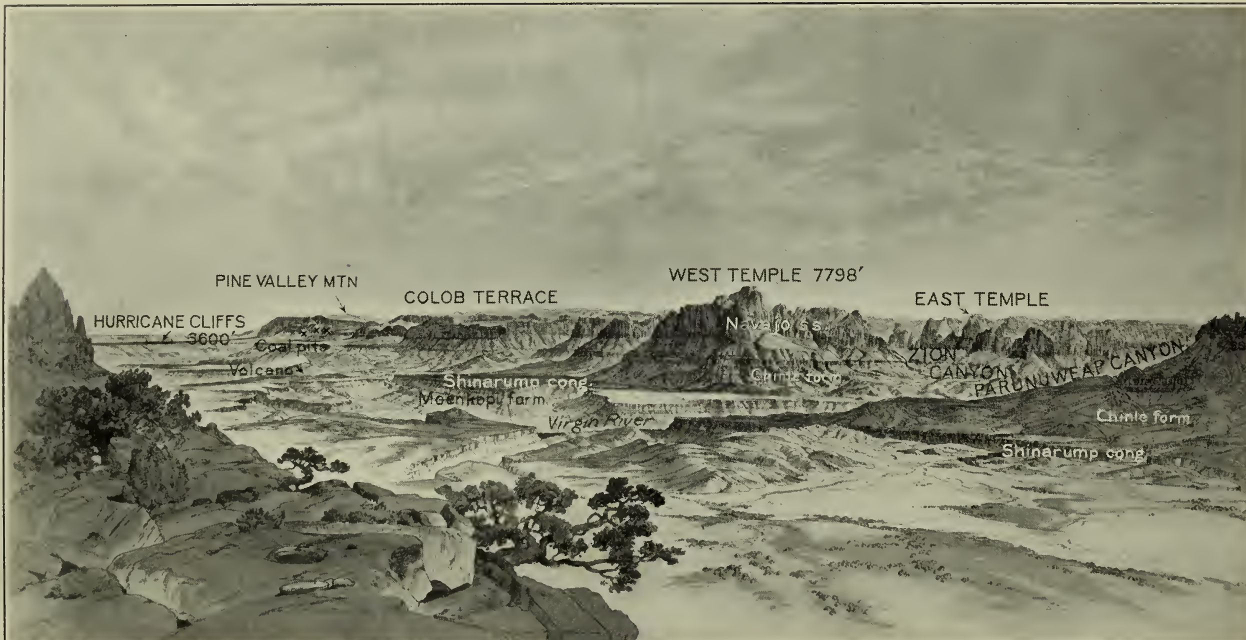


PANORAMIC SKETCHES OF THE EAST KAIBAB MONOCLINE AND ASSOCIATED STRUCTURAL FEATURES, AS VIEWED FROM KAIBAB PLATEAU

Upper view, looking eastward across Marble Platform; lower view, looking southward along the axis of the monocline.



PANORAMIC SKETCH OF THE ZION CANYON REGION

Looking north across the Virgin River from the cliffs south of Rockville. (After Dutton.) Cretaceous coal-bearing rocks in Pine Valley Mountain, west of Hurricane fault.

block have developed a series of steps, and in Parunuweap Valley between Orderville and Glendale beds in the lower block are flexed upward in monoclinal ridges in a fault zone about half a mile wide. Elsewhere short faults of small throw parallel the master fault on both sides. The uplift of the Paunsaugunt block has brought the coal-bearing Cretaceous rocks at Mount Carmel and Glendale into contact with Jurassic? (Navajo) sandstones, indicating a vertical displacement of about 2,000 feet (610 meters). The "White Cliffs," on the skyline east of the Parunuweap, are the continuation of beds on the floor of the valley below Mount Carmel. Northward the throw decreases to about 800 feet (244 meters) along the Sevier River east of Hillsdale. The lateral displacement of beds along the fault is about 9 miles (15 kilometers). Like the Hurricane fault, the Sevier fault cuts the Eocene strata of the "Pink Cliffs," but it seems to be older than the Hurricane. In places the escarpment along the Sevier fault is worn well back, and some of the lava flows that cross the fault line are unbroken. The physiographic history of the Sevier fault as traced by Dutton (8) has been discussed by Davis (7).

PAUNSAUGUNT FAULT

The Paunsaugunt fault follows the east base of the Paunsaugunt Plateau to the head of the Paria Valley and continues northward as the boundary line between the Paunsaugunt Plateau and the Table Cliffs, the southwestern cape of the lofty Aquarius Plateau. Where observed it is a narrow shear zone with few branches and few associated faults. The displacement is estimated as 2,000 feet (610 meters). On the Table Cliffs east of the fault the surface of the Tertiary beds stands at 10,000 feet (3,050 meters); west of the fault at 8,000 feet (2,440 meters). But along the southeast base of the Paunsaugunt Plateau the effects of faulting have been completely obliterated and the normal topography reversed. Erosion in the upthrown block has developed the remarkable Paria Amphitheater, which stands some 2,000 feet (610 meters) below the surface of the downthrown block. (See pl. 3.) The Paunsaugunt fault was partly traced by Dutton (8) and has been described by Gregory and Moore (12).

KAIBAB UPWARP

The Kaibab upwarp is an elongated flat-topped dome ("warped platform," "monoclinal swell," "flattened arch")

with a north-south axis. As a topographic feature it is substantially coextensive with the Kaibab and Coconino Plateaus. (See fig. 5.) From a flat summit at DeMotte Park (altitude 8,900 feet, or 2,715 meters), the surface of the dome slopes north, south, east, and west. Northward the surface rock (Kaibab limestone), slopes about 80 feet to the mile (15 meters to the kilometer) and continues with irregularities for 60 miles (97 kilometers), where it disappears beneath the cliffs bordering the High Plateaus. Southward the slope, at first moderately steep, then nearly flat, may be traced for about 80 miles (130 kilometers). Into this south slope the Grand Canyon has been cut—"a trench across a hillside." (See fig. 4.) The width of the upwarp increases southward from its tapering north end to about 35 miles (56 kilometers) north of the Colorado River and 100 miles (160 kilometers) south of the river, where the uplift

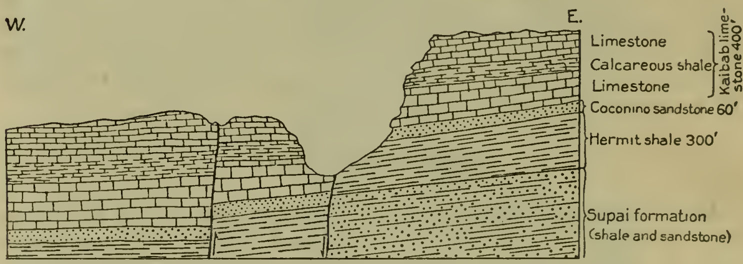


FIGURE 7.—Generalized cross section of West Kaibab fault

appears as a slightly warped plane at an altitude of 7,000 feet (2,133 meters). From its summit westward gentle slopes extend the upwarp to an edge marked by steeply dipping strata cut in places by faults; eastward the nearly flat surface is abruptly replaced by a steep monoclinal fold. The West Kaibab fault (two step faults) at Ryan and Big Springs represents a displacement of about 1,000 feet (305 meters), and this drop, supplemented by downfolding, has brought the surface of the Kanab Plateau some 2,000 feet (610 meters) below the surface of the Kaibab. (See figs. 4 and 7.) As revealed in the walls of the Grand Canyon the West Kaibab fault has been subjected to three separate movements along the same zone—pre-Cambrian, Paleozoic, and Tertiary. The East Kaibab monocline is a narrow belt in which the rocks at the summit of the Kaibab upwarp are downfolded with dips as high as 60°. Throughout most of its extent of about 120 miles (193 kilometers) the monoclinal flexure is simple, but for about 30 miles (48 kilometers) it is double, and where it crosses the Colorado it is

faulted. From the crest of the monocline at Cape Final (altitude 7,919 feet, or 2,414 meters) to the platform adjoining the Marble Gorge there is a drop of about 3,000 feet (915 meters); from the summit of the Kaibab upwarp, it is more than 4,000 feet (1,220 meters)—the measure of the vertical displacement caused by the East Kaibab monocline. (See pl. 4.)

GEOMORPHOLOGY

In very general terms the surface of southern Utah may be described as made up of three long, broad terraces, each ascended by steps. The first terrace, bordering the Grand Canyon, has a floor of Permian (Kaibab) rocks; the second, part way up on the face of the High Plateaus, is developed on Jurassic (Navajo and Carmel) rocks; the third, the top of the High Plateaus, is surfaced by Tertiary (Wasatch) sediments and lavas. From almost any viewpoint long stretches of even skyline may be seen, and distant views give the impression of flat surfaces trenched by canyons. But when the effect of distance is taken into account, the region is seen to possess a ruggedness surpassed by few other places. Though the features of mountainous regions are lacking, a no less pronounced relief is produced by downward departures from a general level. The canyons are so deep and so thickly interlaced that the country seems to be made up of gorges and cliffs, intimately associated with mesas and buttes bounded by steps or vertical walls. Even the stream courses are ungraded, rapids and waterfalls being common. (See pl. 5.)

Erosion is favored by steep gradients, by the composition and attitude of the sedimentary beds, by arid climate, and by sparseness of vegetation—factors that combine to produce denudation probably as rapid as in most humid regions. Through the Grand Canyon the Colorado falls 7.3 feet to the mile (1.37 meters to the kilometer). Its northern tributaries have an average descent of about 25 feet to the mile (4.57 meters to the kilometer). Few of the shorter streams have gradients less than 40 feet to the mile (7.62 meters to the kilometer), and the floors of many broad "washes" fall as much as 15 feet to the mile (2.86 meters to the kilometer). The streams are fed by rains that come usually as violent showers, widely spaced in time and locality. Streams consequently alternate between stages of flood and stages of low water or of flood and dry channel. Except on the surface of the higher plateaus the run-off is little retarded, the area of bare rock exceeding that of vegetation. Erosion is most rapid on cliffs and canyon walls, where rain wash, frost work, and ground-water seepage are especially effective.

To a remarkable degree the development of topography has been controlled by the attitude, structure, and composition of the rocks. Though the Colorado, the Virgin, the Paria and parts of other streams are superposed and thus disregard the structure, Parunuweap, Ash, La Verkin, and Bright Angel Creeks are located partly on faults, and many short streams follow zones of jointing and fissuring. The courses of some streams are determined by the dip slopes of monoclines or the inclination of fault blocks. Regional north and northeast dips, combined with the differences in texture and composition of the strata, have produced the huge rock terraces on the faces of the High Plateaus and on many canyon walls. The giant rock steps displayed along the Virgin River from Hurricane to Mount Carmel (pl. 5) or even better along Kanab and Johnson Creeks are the edges of alternating hard and soft beds. The hard beds make cliffs; the soft beds make slopes that vary in height and steepness with the thickness of their component members. Beginning at the platform developed on Permian (Kaibab) limestone, a slope on Triassic (Moenkopi) shales leads to a cliff sharply cut in Shinarump conglomerate. Above this is the long slope of Triassic (Chinle) shales capped by vertical walls of Jurassic (?) (Navajo) sandstone, impressive alike for height and continuity. From the top of this great cliff a long slope of weak Cretaceous shales leads up to cliffs of hard Cretaceous sandstones over which extend the "Pink Cliffs"—walls of Tertiary limestone that constitute the highest step of a magnificent stairway. (See pl. 5 and fig. 5.)

The streamways across the plateaus are predominantly canyons, most of which meander to a remarkable degree. Many of them head in boxes or amphitheaters and continue their courses between vertical walls. The tributaries enter through slots or spill over the rim as waterfalls. The Paria, the Kanab, and the Virgin, with their larger tributaries, meet their master streams at grade, but hanging valleys appear on the rims of canyons that have cut deeply into thick sandstones. The floors of most of the canyons are ungraded; the streams progress by rapids and falls separated by stretches of steep or flat gradient. Headward cutting by canyon streams of the present cycle has caused much shifting of divides established in the previous cycle. In particular, streams tributary to the Colorado are capturing the headwaters of the Sevier.

Along the Virgin and Kanab conspicuous gravel terraces border the streams. These are remnants of alluvial sheets that recently floored the canyon from wall to wall. As late as 1880 the alluvial fill at Kanab was intact; the canyon bottoms were meadow lands through which streams of clear water flowed.

The change in stream habit from aggrading to degrading has resulted in the destruction of large areas of productive land.

Within the Grand Canyon the erosional processes duplicate those of the adjoining plateaus and are controlled by the same forces. The scenic forms are cliffs, buttes, mesas, and terraces, most of them carved from horizontal beds and developed on a scale that justifies the expression "mountains within a canyon." Because of their different resistance to erosion the beds of limestone, shale, and sandstone present edges arranged as steps ascending the canyon walls and encircling the buttes and mesas. The step developed at the top of the Tapeats sandstone—the Tonto Platform—and that at the top of the Supai formation—the Esplanade—are exceptionally broad and continuous.

In the formation of the Grand Canyon the Colorado River has cut a vertical trench through the 7,000 feet (2,135 meters) of strata now exposed and an even greater thickness of rock that once lay above. But neither to the river itself nor to the streams heading on the adjoining plateaus are to be directly ascribed the amphitheaters and capes, the terraces and temples, that constitute the characteristic features of the canyon. The Colorado is fixed in an inner gorge; valleys on the Kaibab Plateau, though sloping toward the canyon, contribute little water; valleys on the Coconino Plateau slope away from the canyon rim and therefore contribute none. Erosion progresses primarily from below upward as the result of surface water from rains that fall into the canyon and of ground water that passes along bedding planes. The resultant intermittent torrents that flow with steep gradients over bare rock are powerful agents of erosion. Most of the streams are guided in their work by zones of weak rock along short faults of small displacement. The fault in Bright Angel Creek has a throw of about 100 feet (30 meters). Compared with the erosion in progress on the south side of the river, erosion by intracanyon tributaries on the north side is facilitated by a larger supply of water, steeper gradients, and more numerous fracture zones, and the work of ground water is favored by the southwesterly dip of the strata. As a result, the north wall of the canyon has been cut far back and eroded on a stupendous scale. From the river the rim of the Kaibab Plateau is twice as far as the rim of the Coconino Plateau.

So far as interpreted, the morphologic history of the Colorado Plateau country begins with the regional uplift of a broad expanse of Eocene fresh-water sediments, now represented by the cap rocks of the Markagunt and Paunsaugunt Plateaus and forming the "Pink Cliffs." There is reason to believe that the slopes and the inequalities on the surface of this uplifted block

determined the initial position and gradients of the ancestral Colorado and of such equally old streams as the Paria and the Virgin. In their present courses the larger streams are superposed on structural features that have been revealed by erosion. Once established they maintained their courses across folds, faults, and igneous masses, with such shiftings of position and changes in grade as were required for adjustment to new-found conditions. The drainage system thus produced outlined the present great plateaus and canyons, but the steepness and angularity of the cliffs and the depth of the canyons—striking features of the present topography—are the result of a second regional uplift.

The Grand Canyon region has thus witnessed two periods of profound erosion, each initiated by a broad uplift accompanied by faulting and folding. Evidence of the work accomplished during the first period has not been altogether destroyed; the work of the second period is still in progress. In the first period (the "great denudation" of Dutton) a great thickness of the Cenozoic and Mesozoic beds was removed, exposing Permian (Kaibab) rock over an area of about 16,000 square miles (41,400 square kilometers). North of the Colorado River the country was stripped back to the base of the High Plateaus; south of it, to the Aubrey Cliffs. It is believed that during this period, which began in post-Eocene time, the original highlands of southern Utah and northern Arizona were reduced by erosion to a low-lying plain on which the valleys, including that of the Colorado, were shallow and the hills and ridges inconspicuous. Parts of the present surface of the Kaibab, Kanab, Uinkaret, Shivwits, and Coconino Plateaus are thought of as remnants of the plain developed near the end of the first period of erosion. In sharp contrast with adjoining regions they are characterized by broad, shallow valleys and low rounded divides—a mature or even postmature landscape on which drainage is fully developed. That parts of this old surface stood on a level so low and so uniform that the streams lacked the power to intrench themselves is shown by local peneplains preserved beneath lava—peneplains that extend without breaks or significant inequalities across hard and soft rocks and across faults and folds.

The uplifts that introduced the second cycle of erosion ("canyon cycle," the present cycle) raised a series of tilted and slightly warped blocks to a height of 6,000 to 8,000 feet (1,830 to 2,440 meters), thus providing conditions favorable for vigorous erosion. (See fig. 2.) The morphologic evidence for the second uplift is chiefly the readjustment of drainage by shifting of divides, the stripping of talus and accumulated alluvium from cliff faces and lowlands, and the cutting of deep, narrow,

vertical-walled canyons with ungraded floors. The relatively even surface produced during the first period of erosion has been deeply and intricately dissected by streams of the second period.

The two periods of erosion as outlined mark stretches of time during which the conditions were generally favorable for the destruction of high-lying land. There is no reason to believe that the first uplift was accomplished all at one time, that once started it continued at a uniform rate, or that the same climatic conditions prevailed throughout. Gravel-floored rock benches, local peneplains, and perched stream gravel testify to lack of uniformity in tectonic movements or in climate (probably in both) during the second period of uplift and erosion. In recent times parts of many of the canyons have been filled with gravel to depths of 40 to 200 feet (12 to 60 meters), indicating a change from erosion to aggradation. During the last half century removal of the alluvium in these canyons has been in progress. The immediate cause of this channeling that has produced gravel terraces along the canyon streams is generally thought to be overgrazing. With the removal of much of the protective vegetation the run-off became spasmodic and the streams were intermittently given power to remove the valley fill. But the phenomenon is regional and may involve other than human agencies.

Publications on the physiography of the plateau country include those by Powell (24), Dutton (8, 9), Gilbert (10), Davis (6, 7), Huntington and Goldthwait (15), Matthes (18), Gregory (14), Gregory and Moore (12).

ECONOMIC GEOLOGY

The plateau country has been rather thoroughly explored for minerals of economic value. Prospecting has revealed lead and zinc in association with intrusive masses at the Pine Valley Mountains, copper in Jurassic sandstones and Permian limestones, some gold in the region northwest of St. George, asbestos in the Grand Canyon, and widely scattered traces of uranium and vanadium minerals. In the now abandoned mines at Silver Reef, a "ghost city" near Leeds, ore was found in shales and sandstones of the Chinle formation (Triassic) as films and nodules of cerargyrite (horn silver) coating bedding planes, the walls of tiny fissures, and fragments of petrified wood. The silver ore was discovered in 1869, and the value of metals recovered from shallow tunnels and shafts during the period 1875–1890 is reported as $7,127,944. Since 1890, when the oxidized ores were exhausted, silver mining has been unprofitable. At

present the resources exploited in southern Utah are iron, coal, and oil.

The iron mines in the Iron Springs district, about 20 miles west of Cedar City, produce nearly all the iron mined in the United States west of the Rocky Mountains. The ore is hematite and magnetite, intimately intermixed, and has an average iron content of 51.68 per cent. It crops out chiefly in the contact zone between andesite, which constitutes the core of laccoliths, and overlying Carboniferous limestone. Ore from the Iron Springs district has been intermittently mined since its discovery in 1851. During the last few years the ore mined annually has exceeded 320,000 tons (290,300 metric tons), and the pig iron produced 150,000 tons (136,000 metric tons). The reserve of ore is estimated at 40,000,000 tons (36,290,000 metric tons).

More than 4,500,000 tons (4,082,000 metric tons) of bituminous coal from beds of Cretaceous age is mined each year in Carbon County, but elsewhere the coal has been little exploited. In southern Utah outcrops that have been traced from Cedar City to Kanab Creek and are known to extend eastward nearly to the Colorado River indicate an area of "coal lands" estimated at 295 square miles (765 square kilometers) and a body of workable coal estimated at 2,600,000,000 tons (2,358,000,000 metric tons). The coal lies at several different horizons, but most of it is within the lowermost 500 feet (152 meters) of the Cretaceous beds, associated with fossils of Colorado age. At present several small mines provide about 1,000 tons (907 metric tons) of coal each year for local use.

Oil was discovered on North Creek near Virgin City in 1907. In 1921 15 wells were reported; in 1930, 94. From the five wells active in 1930 8,000 barrels (1,272,000 liters) of oil was obtained. Refineries at Cedar City and at Virgin City produce some gasoline, and fuel oil is supplied for local use. The Virgin City oil field lacks the usual geologic structure favorable for the accumulation of oil, and the accumulation seems to have been caused by local steepening of dips (flat to 5° or 6°) that forms steplike wrinkles in beds that have an average dip of about 2°. The source of the oil is a thin bed of cavernous limestone near the base of the Moenkopi formation. Wells sunk in the series of domes extending from Toquerville southward to and beyond the Utah-Arizona line have not proved commercially productive.

Detailed descriptions of metal-mining districts in Utah are given by Butler (3). Reports on iron of the Iron Springs district have been written by Leith and Harder (16), on coal in the southern High Plateaus by Richardson (26), and on the oil fields of Washington County by Bassler and Reeside (2).

ITINERARY

A. CEDAR CITY TO ZION CANYON, GRAND CANYON, BRYCE CANYON, CEDAR BREAKS; RETURN TO CEDAR CITY

Cedar City to Zion Lodge, Zion National Park (66 Miles, or 106 Kilometers)

(1)[2] Cedar City (settled 1851; population 7,227; altitude 5,840 feet, or 1,780 meters). On oasis at mouth of Coal Canyon, at end of railroad that serves Utah and Arizona north of the Colorado River. Supply point and shipping point; center for stock raising and small-scale irrigation agriculture. Iron mines 20 miles (32 kilometers) west; coal mines 10 miles (16 kilometers) east. The city is on the downthrown block of the Hurricane fault, which here marks the division between the Great Basin country and the High Plateaus.

From Cedar City to Anderson Junction (34 miles, or 55 kilometers) the road traverses a dissected plain between the Hurricane escarpment at the base of the Markagunt Plateau and Colob Terrace on the east and the West Mountains and Pine Valley Mountains on the west. North of Kanarraville (miles 4 to 14) is a "fault valley" filled with alluvium, 200 to 400 feet (61 to 122 meters). Kanarraville is on the drainage divide between the Great Basin and the Colorado River. From Ash Creek (mile 20) southward the road is on lava, and near by there are andesite intrusives on both sides of the road.

(2) Rise in road 2 miles (3.2 kilometers) south of Pintura (Bellevue; Midway). In the foreground the basalt floor is trenched by tributaries to Ash Creek. To the west are the Pine Valley Mountains, containing folded Mesozoic strata, Paleozoic (?) strata, and intrusives capped by "trachyte"; to the east is the escarpment of the Hurricane fault made of eastward-dipping Permian and Triassic strata with beveled edges capped by basalt. Basalt in the foreground and on top of the escarpment once formed continuous sheets, now separated by a break of about 1,500 feet (457 meters). Landslides are seen on the cliff face.

From Anderson Junction to the base of the Hurricane Cliffs at La Verkin (miles 34 to 41) the road crosses the north end of an anticline of Jurassic rocks west of Toquerville (settled in 1858); it also crosses Ash and La Verkin Creeks, which have intrenched themselves in lava deposited on ancient river gravel.

(3) Base of Hurricane Cliffs, near junction of La Verkin-Zion road, on downthrown block of Hurricane fault. To the east is the Hurricane escarpment of Kaibab (Permian) strata overlain in places by basalt; to the south are lava fields, the downthrown

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[2] Numbers refer to Plate 1.

part of the sheets that cap the escarpment; to the west is the east limb of an anticline that includes the topmost Jurassic beds; to the north is the continuation of the Hurricane escarpment along the main fault passing west of Toquerville Hill and an anticlinal fold between La Verkin and Ash Valleys.

(4) Crest of Hurricane Cliffs (mile 43). On the west are lava flows on La Verkin Creek, beyond them fossiliferous Jurassic beds on the east limb of an anticline, and in the distance Navajo (Jurassic?) at the base of the Pine Valley Mountains. To the north the Moenkopi (Triassic) is downwarped. To the southwest, across the Virgin River, is a recent volcanic cone, and beyond it red sand dunes.

(5) East slope of Hurricane Cliffs (mile 44), view of strata from Kaibab (Permian) to Navajo (Jurassic?) on both sides of the Virgin River. The first bench (at the road) is on the Kaibab limestone; the second bench on the limestones in the Moenkopi formation; the third on Shinarump conglomerate (Triassic); the upper slope is Chinle (Triassic); the towers at the top, the Navajo sandstone (Jurassic?) of Zion Canyon. (See pl. 5.)

From the Hurricane Cliffs to the mouth of the Parunuweap (16 miles, or 26 kilometers) the road runs on Moenkopi strata. For 6 miles (9.6 kilometers) lava from a near-by cone caps the cliffs at the north. There is an oil field 1½ miles (2.4 kilometers) northeast of Virgin City. Between Virgin City and Rockville the removal of valley fill by the Virgin River has destroyed settlements established in 1861–1863.

(6) Mouth of the Parunuweap branch of the Virgin River 1 mile (1.6 kilometers) east of Rockville (settled 1862; population 251). Contact of Moenkopi and Shinarump.

From the mouth of the Parunuweap through Springdale to the mouth of Zion Canyon the cliffs on both sides of the road are Chinle (Triassic) capped by massive Jurassic (?) sandstones (Wingate and Navajo).

(7) Zion Canyon, the canyon of the Mukuntoweap (moo-kun′toe-weep) branch of the Virgin River. Chinle strata at entrance; Navajo at and beyond Zion Lodge. Short trips within the canyon, including a visit to the museum, will be arranged. Descriptive pamphlets are available.

Zion Lodge to Grand Canyon (124 Miles, or 200 Kilometers)

From Zion Lodge the road is retraced to the entrance of Zion Canyon, thence ascends Pine Creek through tunnels and cuts to the top of the Markagunt Plateau and follows the Mount Carmel highway to the Parunuweap Valley. (Road opened 1930.)

(8) West end of first tunnel. View of strata composing walls of Zion Canyon, showing relation of beds and method of erosion.

(9) Windows in highway tunnel. Details of structure of massive Navajo sandstone and of erosion. (Walk from window 5 to window 6.)

(10) About 300 feet (90 meters) east of Kane-Washington County line. Cross-bedding in Navajo sandstone.

(11) Road junction 4 miles (6.4 kilometers) east of Kane-Washington County line. Cut in road shows Carmel limestone (Jurassic) that overlies the temples at Zion Canyon. To the west, Navajo sandstone; to the north, Cretaceous.

(12) Meadow Brook Canyon. Southward downstream are exposed Navajo, Carmel, and undifferentiated shales, sands, and gypsum (topmost Jurassic). To the east the Jurassic is overlain by a gravel bed in the position of the Dakota (?) sandstone and by coal-bearing Cretaceous shales. Along the road coal is exposed at the bridge and Dakota (?) gravel 1 mile (1.6 kilometers) to the east.

From the east wall of Meadow Brook Canyon to Mount Carmel Junction, in Parunuweap Valley, the road is on Upper Jurassic rocks, well displayed in road cuts. Distant view eastward shows "White Cliffs" (Navajo) uplifted on the east side of Sevier fault; to the north are Cretaceous beds. Southward from Mount Carmel Junction the road ascends the east wall of Parunuweap Canyon through cuts in the Navajo and Carmel formations, across the Sevier fault, over a flat divide to Kanab Creek, thence between walls of Jurassic and Triassic rock to the village of Kanab. Recent trenching of valley fill is well developed in Kanab Canyon.

(13) West slope of divide between Virgin River and Kanab Creek, 3 miles (4.8 kilometers) from Mount Carmel Junction. To the northeast the "White Cliffs" (upper part of Navajo, capped by Carmel) form an escarpment along the Sevier fault; to the southwest the Sevier fault zone is marked by lowlands (Cane Flats) and breaks in cliffs; to the west, across Carmel strata, trenched by the canyon of the Parunuweap, the view embraces the walls of Zion Canyon; to the northwest are Cretaceous shales and sandstones capped by Tertiary limestone.

(14) Kanab Canyon just below lakes in Three Lakes Canyon. Display of cross-bedding in sandstone.

(15) Kanab (settled 1864; population 1,195; altitude 4,925 feet or 1,500 meters). Cliffs of Chinle (Triassic) at north.

From Kanab southward the road traverses a flat developed on Chinle shales, crosses a ridge of Shinarump conglomerate, and continues through Fredonia over Moenkopi (Triassic) beds to the Kaibab limestone, which is the surface rock from the west

base of the Kaibab Plateau to the Grand Canyon. Some of the many "sink holes" on the Kaibab Plateau are occupied by ponds.

(16) Ridge of Shinarump conglomerate 0.7 mile (1.1 kilometers) south of Utah-Arizona boundary line. To the north, the "Vermilion Cliffs" (Chinle capped by Jurassic sandstone), with "White Cliffs" in distance; to the west the cliffs show offset along Sevier fault; to the south and east Moenkopi strata extend to contact with Kaibab limestone of Kanab Plateau (south) and Kaibab Plateau (east distance).

(17) West slope of Kaibab Plateau, 3.3 miles (5.3 kilometers) east of Ryan Junction. To the north, view of steplike cliffs developed in northeastward dipping strata, Triassic to Tertiary; to the west, across Kaibab and Moenkopi strata of Kanab Plateau, is Mount Trumbull. (See fig. 6.)

(18) Grand Canyon Lodge (altitude 8,300 feet, or 2,530 meters).

Grand Canyon

Trips to viewpoints on canyon rim. Detailed descriptions will be found in the publications of the National Park Service.

Grand Canyon to Bryce Canyon (164 Miles, or 264 Kilometers)

From Grand Canyon Lodge to Mount Carmel Junction the route is retraced along the crest and down the west slope of the Kaibab Plateau (Kaibab limestone), across the "Prismatic Plains" (Moenkopi), over the ridge of Shinarump north of Fredonia, through Chinle shales and Jurassic sandstones along Kanab Creek, across Sevier fault, and down the walls (Upper Jurassic) of Parunuweap Canyon.

(19) De Motte Park; V. T. ranch (altitude 8,700 feet, or 2,650 meters). Valley on the crest of the Kaibab upwarp. Viewpoint 2 miles (3.2 kilometers) east shows Kaibab monocline, Marble Platform, Marble Gorge of the Colorado, Echo Cliffs, and Navajo Mountain. (See pl. 4.)

(20) Cut in road 0.3 mile (0.48 kilometer) north of Mount Carmel Junction (altitude 5,325 feet, or 1,623 meters). Jurassic shales, limestone, gypsum. To the north, Cretaceous shales dipping northeast; to the east, across the river, cliffs of Navajo sandstone (altitude 6,500 feet, or 1,980 meters) in upthrown block of Sevier fault that runs near their base; distant view, Tertiary (altitude 9,000 feet, or 2,745 meters).

From Mount Carmel village through Orderville to Glendale, Cretaceous shales (well displayed at Orderville) and overlying sandstone form the west bank of the Parunuweap; the east wall is the escarpment of the Sevier fault.

(21) Gap in road 1 mile north of Orderville (settled 1875; population 439). Monocline of Navajo and Carmel strata along fracture parallel to Sevier fault.

(22) Glendale (settled 1864; population 239). The Sevier fault cuts the east canyon wall, bringing coal-bearing Cretaceous against Jurassic (Carmel) limestone.

From Glendale to Long Valley Junction (14 miles, or 22.5 kilometers) the road passes between walls of Cretaceous rock and then upward into Tertiary sediments. Lava caps the cliffs in places and at 6.5 miles (10.4 kilometers) north of Glendale rests on alluvium within the canyon. Limestone of the "Pink Cliffs" is exposed in tributary canyons.

(23) Long Valley Junction (altitude 7,500 feet, or 2,290 meters). Divide between Virgin and Sevier river systems. In the foreground and to the southwest the plateau top is the downthrown block of the Sevier fault. To the northeast Tertiary strata of the "Pink Cliffs" form the upthrown block of the Sevier fault, bordered on the west by Cretaceous sandstones.

From Long Valley Junction to Bryce Canyon (41 miles) the road follows the Sevier River across the eastward-dipping Markagunt Plateau to Bryce Junction (altitude 6,600 feet, or 2,010 meters) thence eastward across the Sevier fault and up Red Canyon (Tertiary limestone) to the top of the Paunsaugunt Plateau (altitude 8,000 to 9,000 feet, or 2,440 to 2,745 meters). The Sevier River has developed erosion surfaces at two levels. Lava caps the upper level 1½ miles (2.4 kilometers) south of Hatch and between Hatch and Hillsdale.

(24) Bryce Canyon (altitude 8,000 feet, or 2,440 meters). (See pl. 3.) Short trips to viewpoints. Detailed descriptions will be found in publications of the National Park Service.

Bryce Canyon to Cedar City (88 Miles, or 141.6 Kilometers)

From Bryce Canyon to Long Valley Junction the route is retraced. From Long Valley Junction westward the road ascends the dip slope of Tertiary strata of the Markagunt Plateau (altitude 7,500 to 10,400 feet, or 2,290 to 3,170 meters), thence through Cretaceous and older strata down Coal Canyon to Cedar City (5,840 feet, or 1,780 meters). The maturely eroded surface is covered in many places by recent basalt flows, which have obstructed the slow moving, meandering streams.

(25) Navajo Lake (altitude 9,500 feet, or 2,895 meters). Drainage channel blocked by lava.

(26) Cedar Breaks (altitude 10,400 feet, or 3,170 meters). Luncheon stop. Fantastically eroded Tertiary limestone. View westward is down Parowan Creek across Tertiary, Creta-

ceous, Jurassic, and Triassic strata to the Hurricane fault. In the distance are ranges and flats of the Great Basin.

(27) Viewpoint 5 miles (8 kilometers) from Cedar Breaks, 1 mile (1.6 kilometers) west of road summit (altitude 9,900 feet, or 3,018 meters). Southward extend Cretaceous and Jurassic rocks deeply trenched by tributaries to Zion Canyon.

The road down Coal Creek crosses the edge of Tertiary strata to a flat 6 miles (9.6 kilometers) long developed at the top of Cretaceous beds. Beyond this the narrow canyon is cut in Cretaceous sandstone for a distance of about 4 miles, then passes through faults and steeply folded Jurassic and Triassic rocks, and terminates at the Hurricane fault scarp 1 mile east of Cedar City.

(28) Jurassic rocks 2.5 miles (4 kilometers) east of Cedar City. Navajo and underlying formations steeply folded; topmost Jurassic downthrown on the east.

B. WINSLOW, ARIZONA, TO FLAGSTAFF, TUBA CITY, GRAND CANYON

By Harold S. Colton and Richard M. Field

Among the geologic reports on this region are those by Darton (4, 5), Robinson (27), and Gregory (14). Several papers on archeology have been prepared by the Bureau of American Archeology.

Winslow to Flagstaff

[Pl. 6]

20[3] Gillespie oil well, at Sunshine. Never produced.

27 Meteor Crater. This crater is a subject of controversy. By one group it is believed to have been formed by one huge meteor which exploded upon impact. The so-called "Diablo" iron is represented by numerous fragments weighing from a few ounces to several tons. These have been found in the crater and also scattered around the rim. The main body of the supposed meteorite has not been found, although there have been extensive mining operations. By a second group the crater is believed to be the result of a steam explosion connected with some of the late volcanic activities in the region, and the presence of considerable meteoric material is interpreted as an accidental circumstance.

33 Canyon Diablo, a canyon in the Kaibab limestone.

[3] Figures indicate mileage.

44 Wilson Pueblo, probably the oldest house standing in the open in the United States. About 900 A. D., as dated by the chronology worked out for the region by Dr. A. E. Douglass from the study of annual growth rings of trees.
45 Canyon Padre, a canyon in the Kaibab limestone.
46–50 Ash dunes from the eruption of Sunset Crater. Eruption occurred just before 800 A. D.
53 Walnut Creek, a canyon blocked by late volcanic débris.
58 Turkey Hill Pueblo ruin, one-fourth mile (0.4 kilometer) south of road. Occupied from 1200 to 1290 A. D. Large ash dune by roadside.
61 Elden Pueblo ruin. Occupied in the twelfth and early thirteenth centuries.
62 Elden Mountain laccolith. Redwall limestone, Supai sandstone, Coconino sandstone, and Kaibab limestone. Upended on the east side.
69 Quarry in the Moenkopi 1 mile east of Flagstaff.
70 Flagstaff; visit to the Lowell Observatory and the Museum of Northern Arizona.

Flagstaff to Tuba City

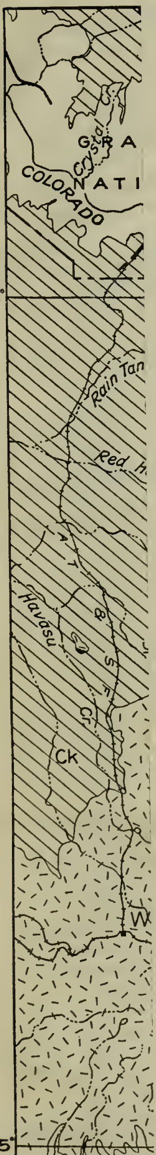
1 Quarry, Moenkopi sandstone.
5 Elden Mountain laccolith.
7 Elden Pueblo. Old caves; a pueblo ruin on the top of a cinder cone. 1200 to 1300 A. D.
10 Black Bill Park.
12.5 San Francisco Peaks to the west; view into the Interior Valley.
17 Sunset Crater National Monument. Bonito lava flow, fumaroles. The most recent evidence of volcanic activity in the San Francisco Mountain region. (The eruption of Sunset Crater will shortly be dated by the tree-ring method from charcoal recovered from the excavations. Dr. A. E. Douglass is working on the material. The date will probably be found to be around 800 A. D.)
21 Excavations in the volcanic ash revealing buried habitations of early pueblo peoples.
26 Excavations in later sites near Deadmans Flat.
39 Wupatki National Monument, citadel ruins, 1100 to 1200 A. D. Faults and solution cracks in the limestone.
56 Little Colorado monocline, Moenkopi sandstone and Shinarump conglomerate.

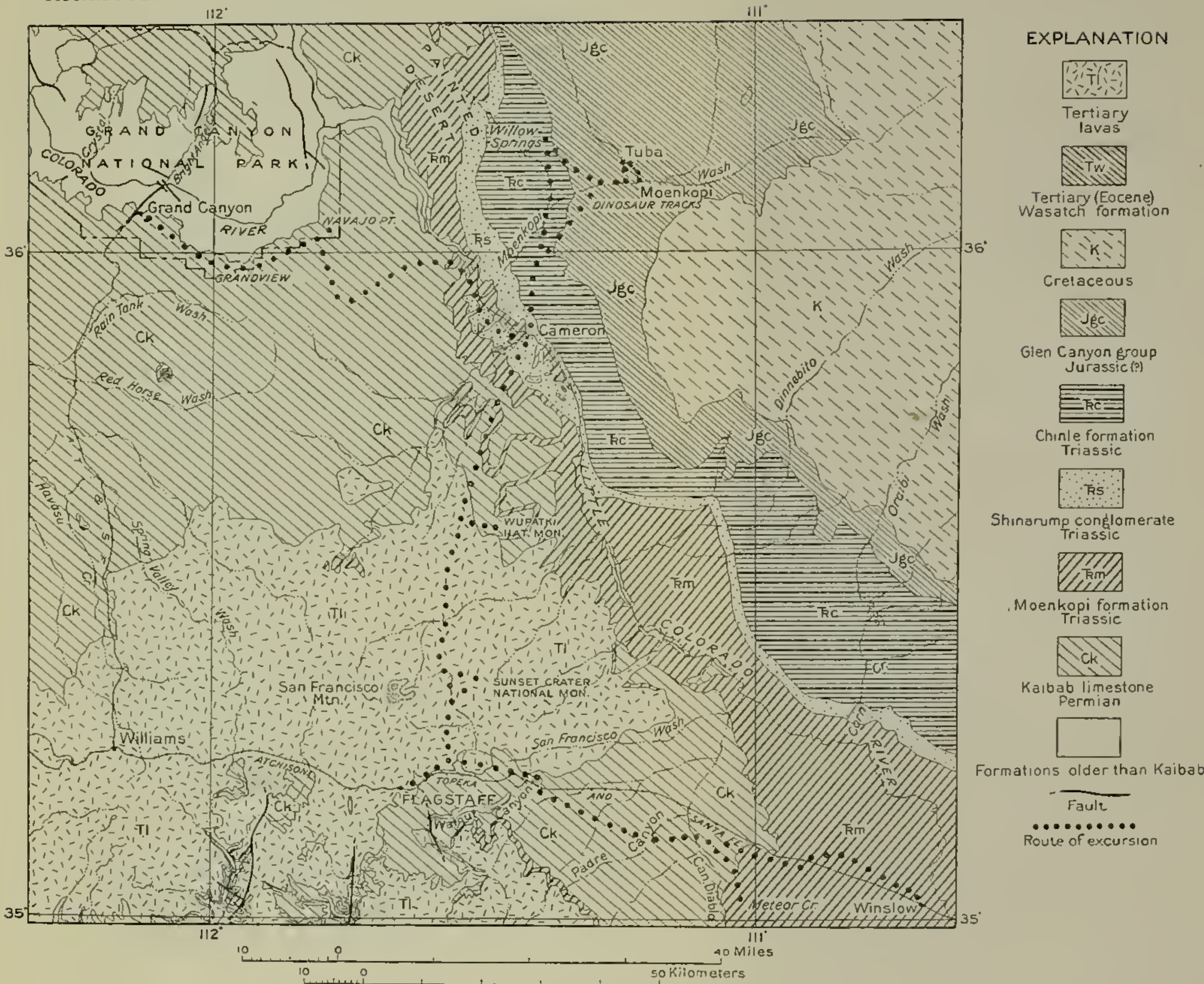
69 Cameron Indian trading store; labyrinthodont tracks built into the building. Twelve miles (19 kilometers) southeast lies Dinosaur Canyon. Many tracks in the Wingate (?) sandstone.
85 Dinosaur tracks by the Tuba City road. Chinle formation.
92 Hopi Indian Pueblo of Moenkopi.
94 Tuba City Navajo Indian School. Charlie Day Spring, from which Pleistocene mammals were recovered in 1929: *Elephas columbi*, *Camelops*, *Equus*, and *Bison antiquus*.

Tuba City to Grand Canyon

10 Picture Rock at Willow Springs. Carvings made by Hopi Indians from about 1300 to the present day.
20 Petrified forest in the Chinle formation (Triassic). Same horizon as petrified forest at Adamana.
37 Cameron Indian trading store.
38.5 Quaternary lava flow in the side canyon.
41 Labyrinthodont tracks 2 miles (3.2 kilometers) south of road.
43 Melgosa Petrified Forest in Shinarump conglomerate.
45 Solution cracks in Kaibab limestone.
47 Coconino Point, monocline and fault.
52 Canyon of the Little Colorado. An illustration of an intermittent stream and desert erosion.
75 Navajo Point, "Desert View." Greatest observable thickness of the Algonkian.
77 Lippan Point Pueblo ruin.
88 Grand View Point. View showing the "wedge" of the Algonkian and its relation to underlying Vishnu schist and overlying Paleozoic rocks.
103 Grand Canyon.

COLORADO P





MAP OF ROUTE FROM WINSLOW TO GRAND CANYON

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